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Haddad

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(54) **METHODS AND SYSTEMS FOR MOBILE IP ROUTE OPTIMIZATION**

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H04W 8/08	(2009.01)
H04L 29/06	(2006.01)
H04W 80/04	(2009.01)

(52) **U.S. Cl.**
CPC ***H04W 8/082*** (2013.01); *H04L 63/04* (2013.01); *H04L 63/0869* (2013.01); *H04L 63/164* (2013.01); *H04W 80/04* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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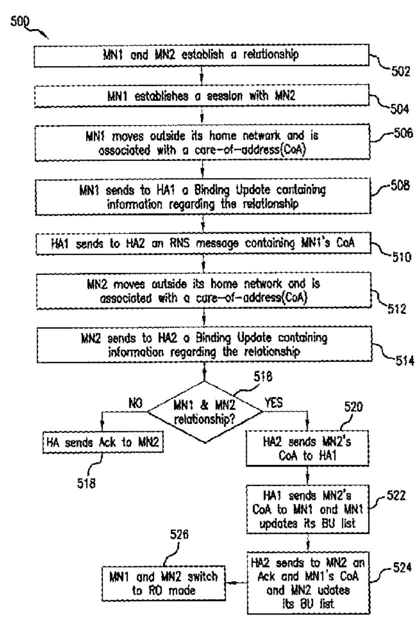
Primary Examiner — Jackie Zuniga Abad

(57) **ABSTRACT**

The present application relates to network mobility (e.g., mobility in an IPv6 network). More specifically, the present application discloses systems and methods for enabling mobile nodes to switch to a routing optimization mode using a minimum of mobility messages.

30 Claims, 14 Drawing Sheets



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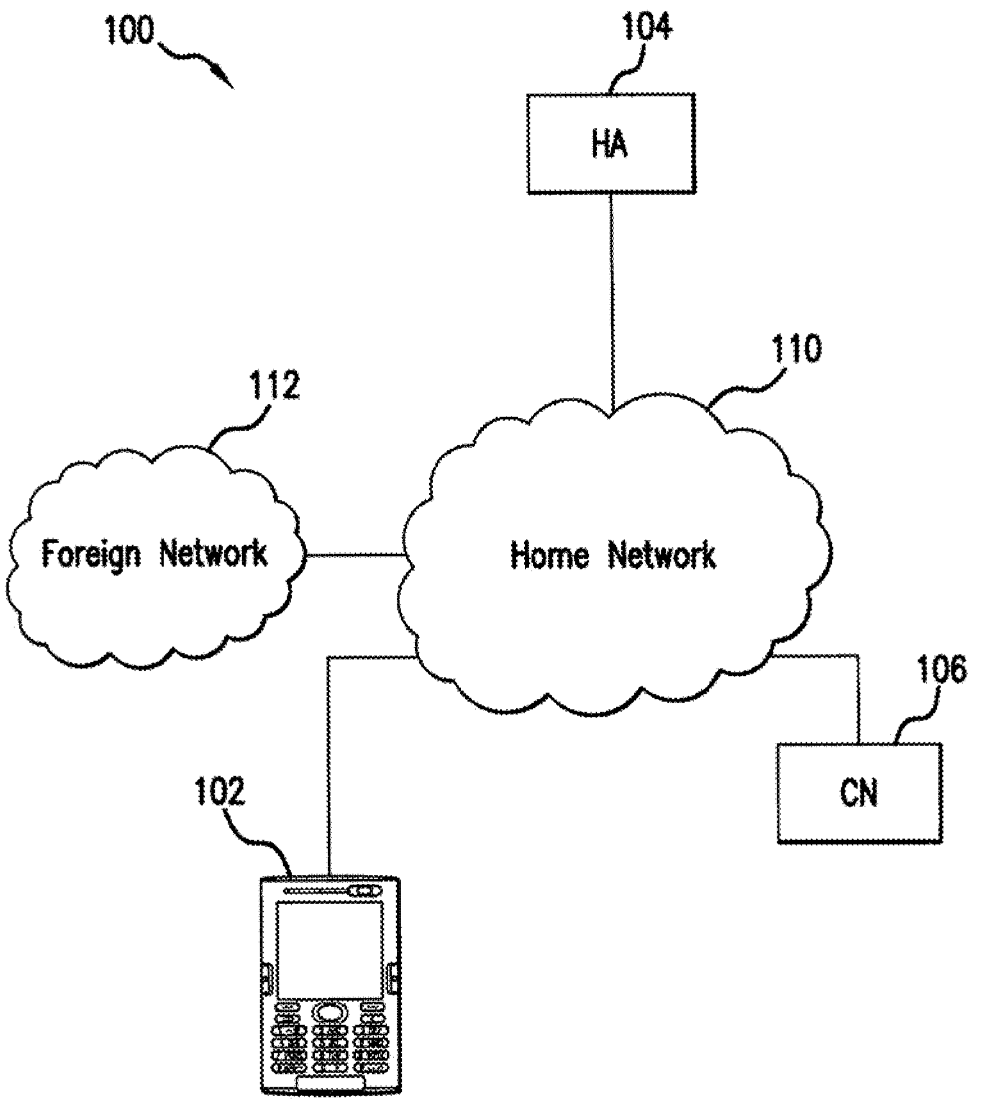

FIG.1

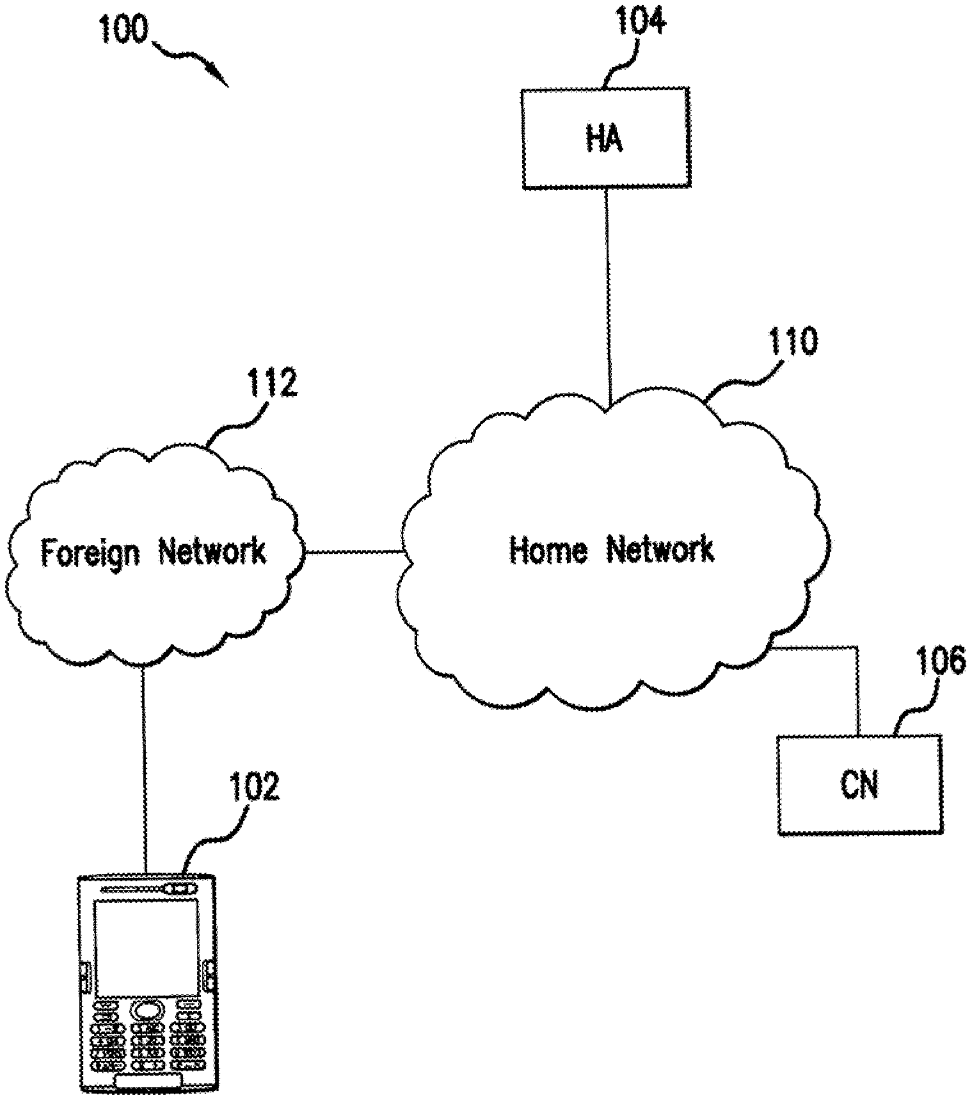

FIG. 2

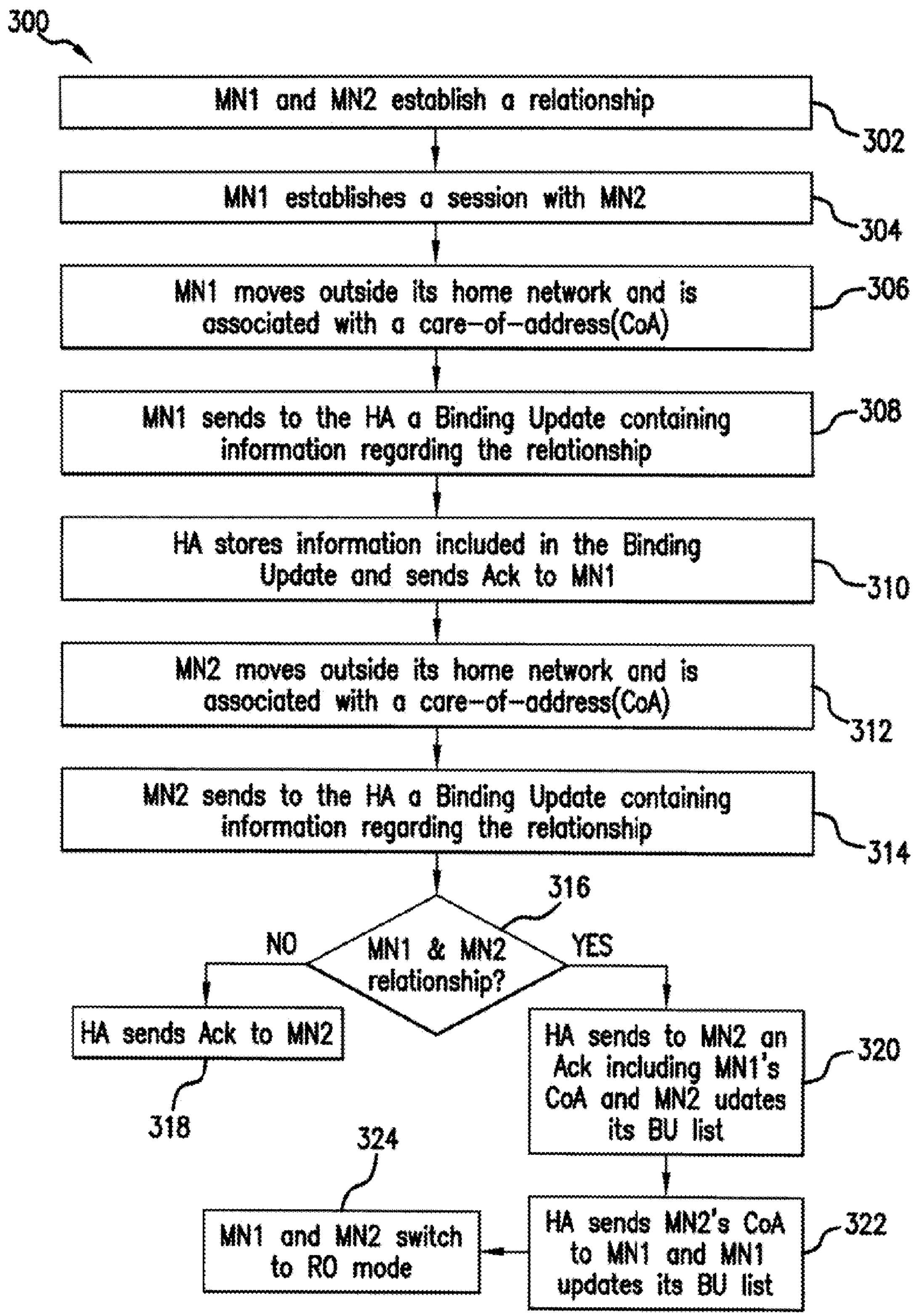
300
MN1 and MN2 establish a relationship
302
MN1 establishes a session with MN2
304
MN1 moves outside its home network and is associated with a care-of-address(CoA)
306
MN1 sends to the HA a Binding Update containing information regarding the relationship
308
HA stores information included in the Binding Update and sends Ack to MN1
310
MN2 moves outside its home network and is associated with a care-of-address(CoA)
312
MN2 sends to the HA a Binding Update containing information regarding the relationship
314
316
MN1 & MN2 relationship?
NO
YES
HA sends Ack to MN2
318
HA sends to MN2 an Ack including MN1's CoA and MN2 udates its BU list
320
HA sends MN2's CoA to MN1 and MN1 updates its BU list
322
MN1 and MN2 switch to RO mode
324

FIG.3

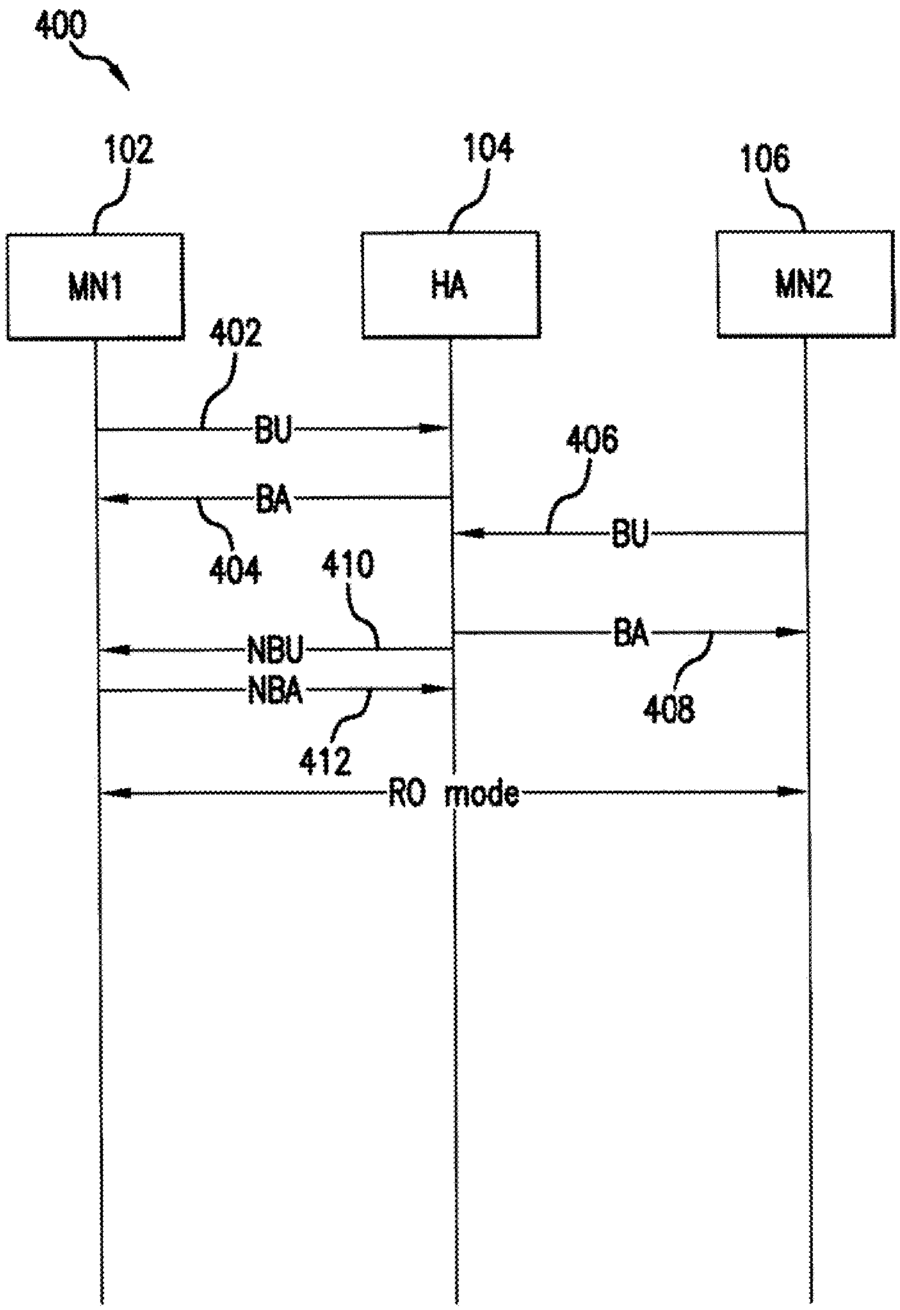
400
102
104
106
MN1
HA
MN2
402
BU
406
BA
BU
404
410
BA
NBU
NBA
408
412
RO mode

FIG.4

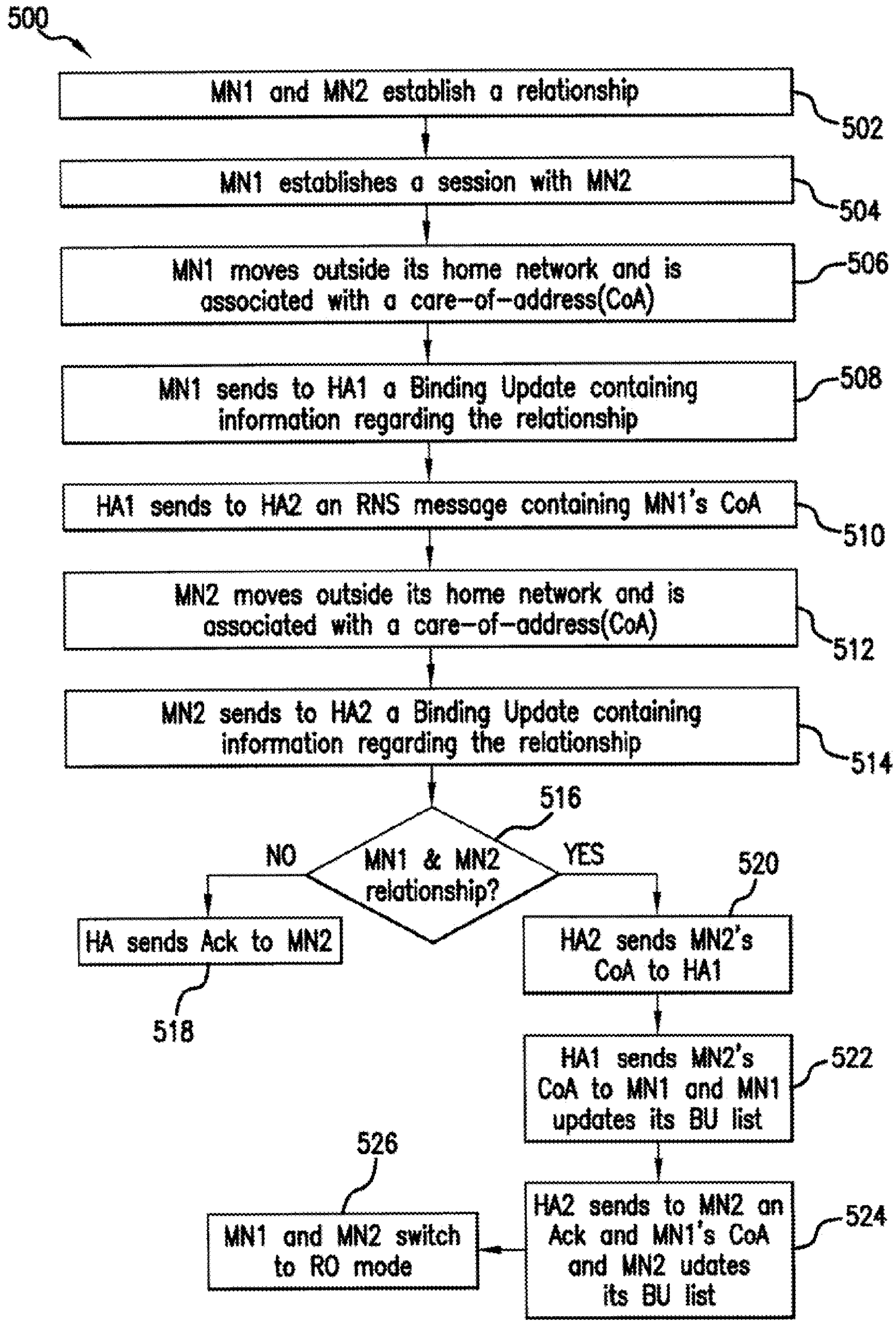
500
MN1 and MN2 establish a relationship
502
MN1 establishes a session with MN2
504
MN1 moves outside its home network and is associated with a care-of-address(CoA)
506
MN1 sends to HA1 a Binding Update containing information regarding the relationship
508
HA1 sends to HA2 an RNS message containing MN1's CoA
510
MN2 moves outside its home network and is associated with a care-of-address(CoA)
512
MN2 sends to HA2 a Binding Update containing information regarding the relationship
514
516
MN1 & MN2 relationship?
NO
YES
HA sends Ack to MN2
518
520
HA2 sends MN2's CoA to HA1
HA1 sends MN2's CoA to MN1 and MN1 updates its BU list
522
526
MN1 and MN2 switch to RO mode
HA2 sends to MN2 an Ack and MN1's CoA and MN2 udates its BU list
524

FIG.5

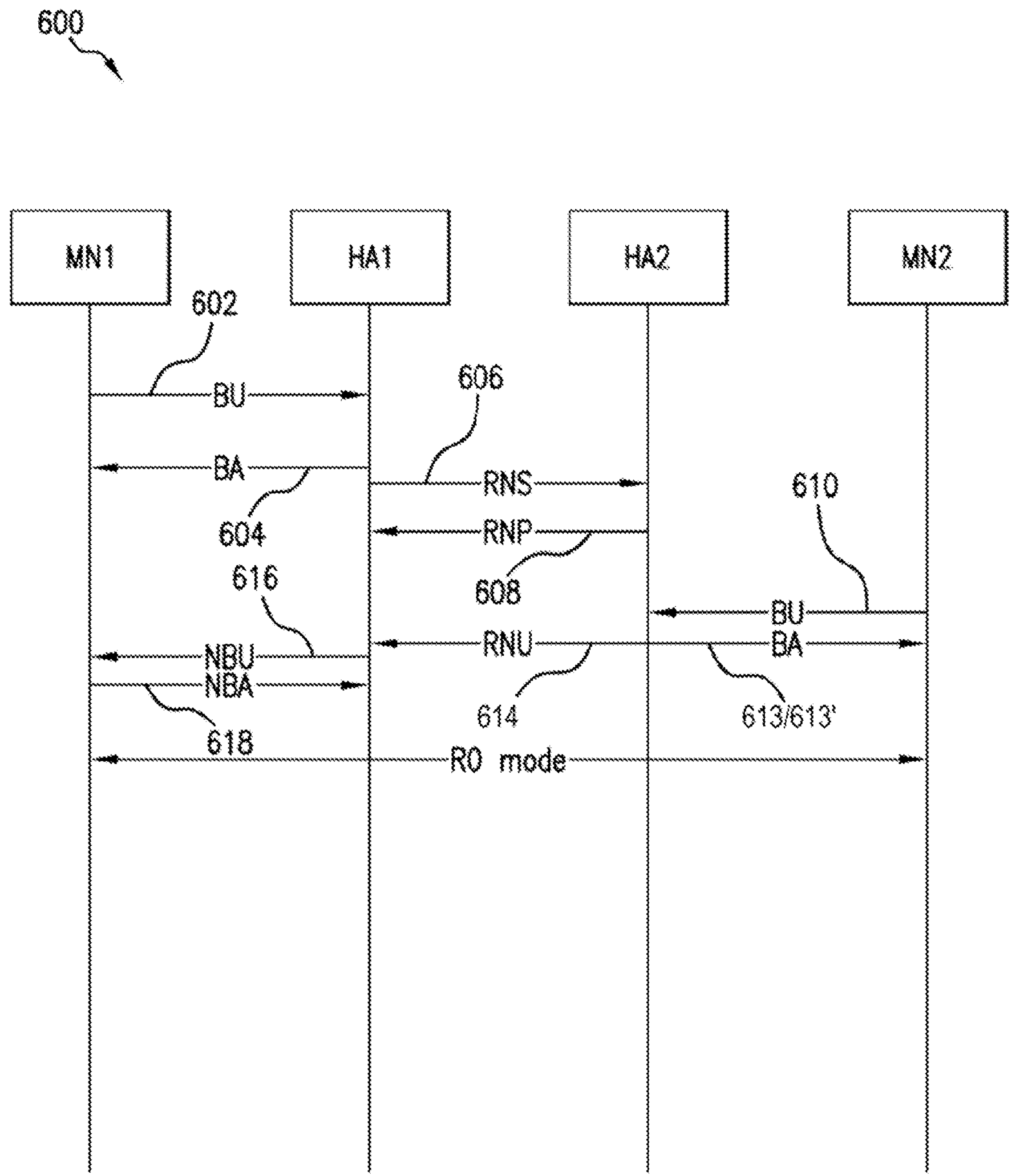
600
MN1
HA1
HA2
MN2
602
BU
606
BA
RNS
610
604
RNP
616
608
BU
NBU
RNU
BA
NBA
614
613/613'
618
RO mode

FIG.6

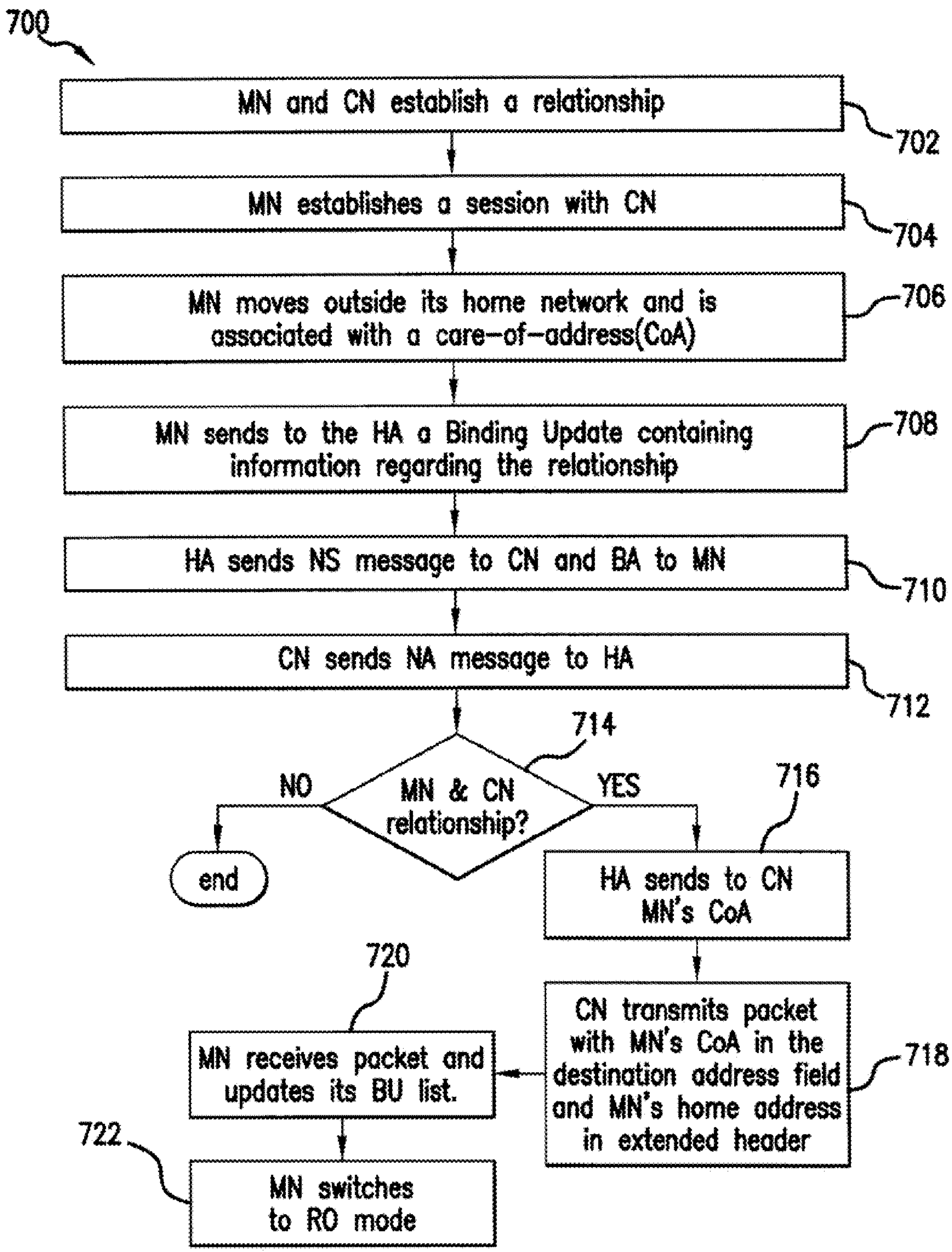
700
MN and CN establish a relationship
702
MN establishes a session with CN
704
MN moves outside its home network and is associated with a care-of-address(CoA)
706
MN sends to the HA a Binding Update containing information regarding the relationship
708
HA sends NS message to CN and BA to MN
710
CN sends NA message to HA
712
MN & CN relationship?
714
NO
YES
end
HA sends to CN MN's CoA
716
CN transmits packet with MN's CoA in the destination address field and MN's home address in extended header
718
MN receives packet and updates its BU list.
720
MN switches to RO mode
722

FIG.7

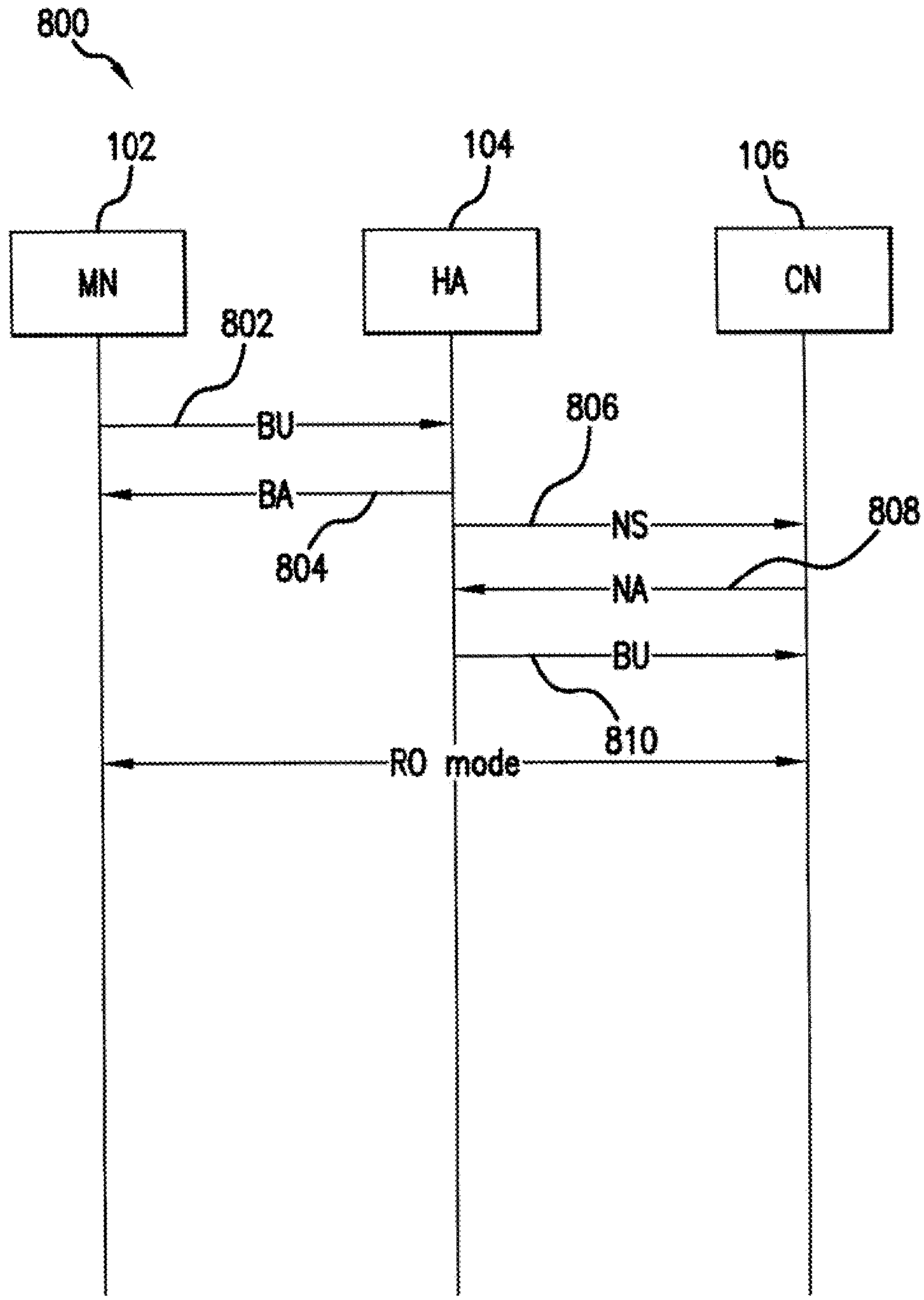

FIG.8

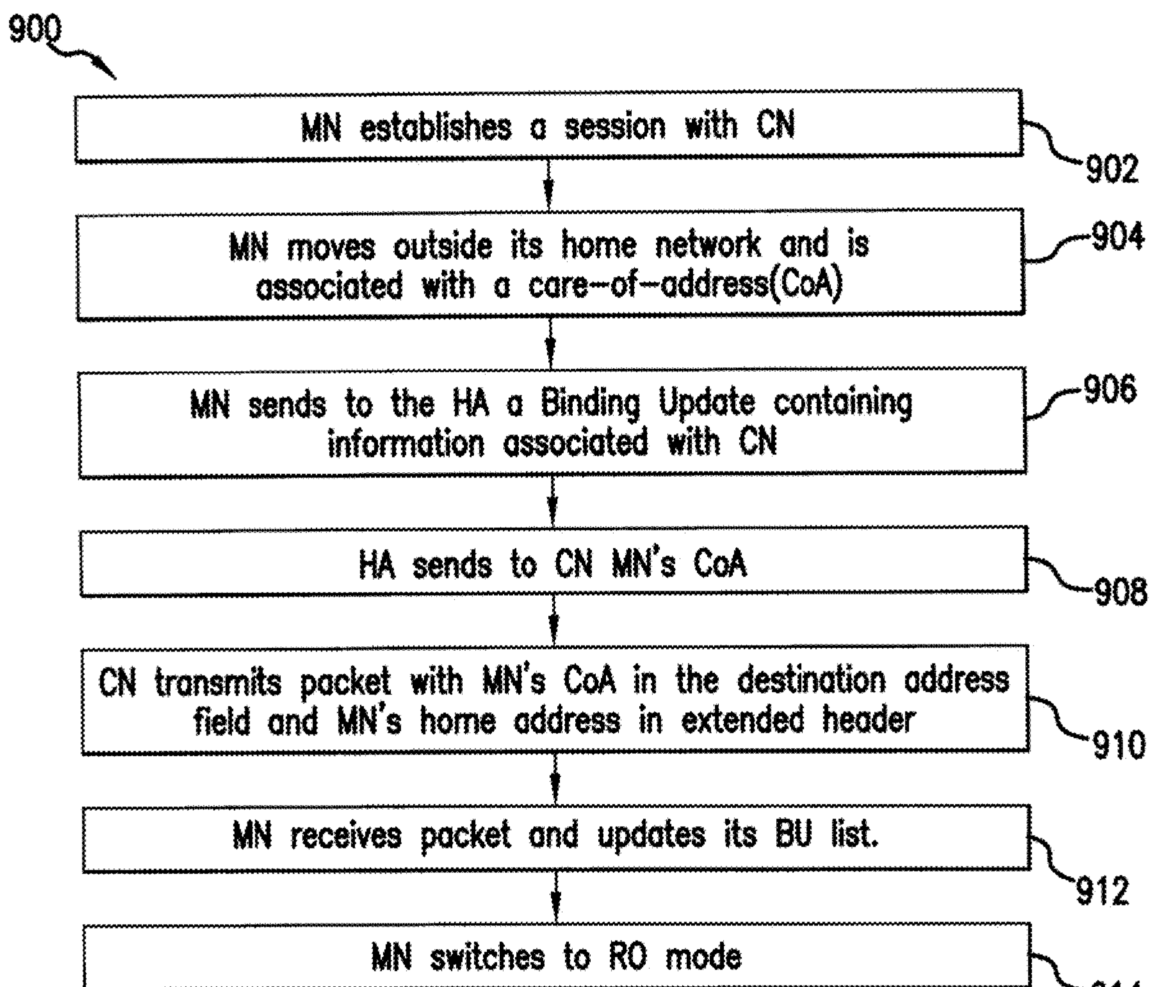
900
MN establishes a session with CN
902
MN moves outside its home network and is associated with a care-of-address(CoA)
904
MN sends to the HA a Binding Update containing information associated with CN
906
HA sends to CN MN's CoA
908
CN transmits packet with MN's CoA in the destination address field and MN's home address in extended header
910
MN receives packet and updates its BU list.
912
MN switches to RO mode
914

FIG.9

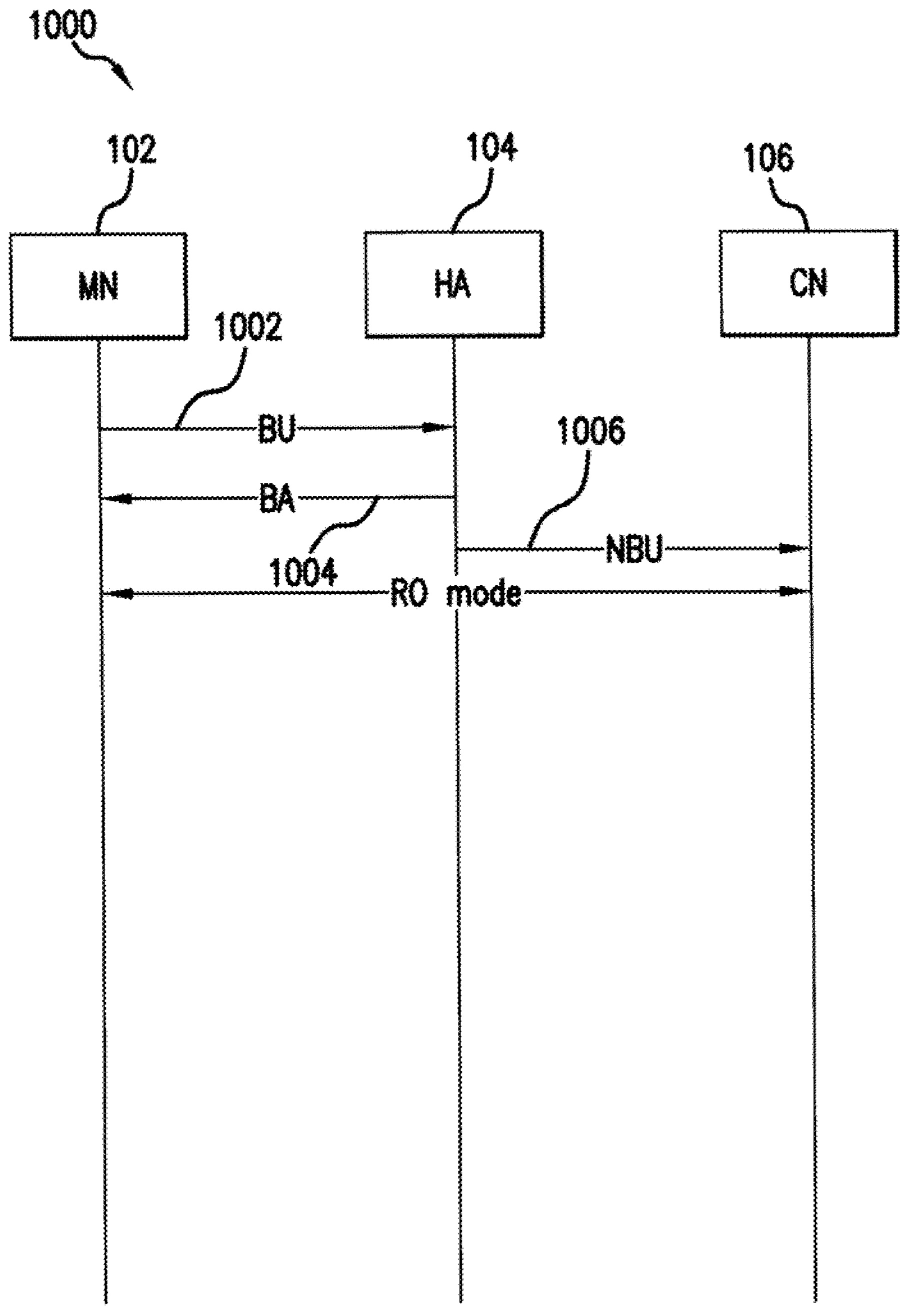

FIG. 10

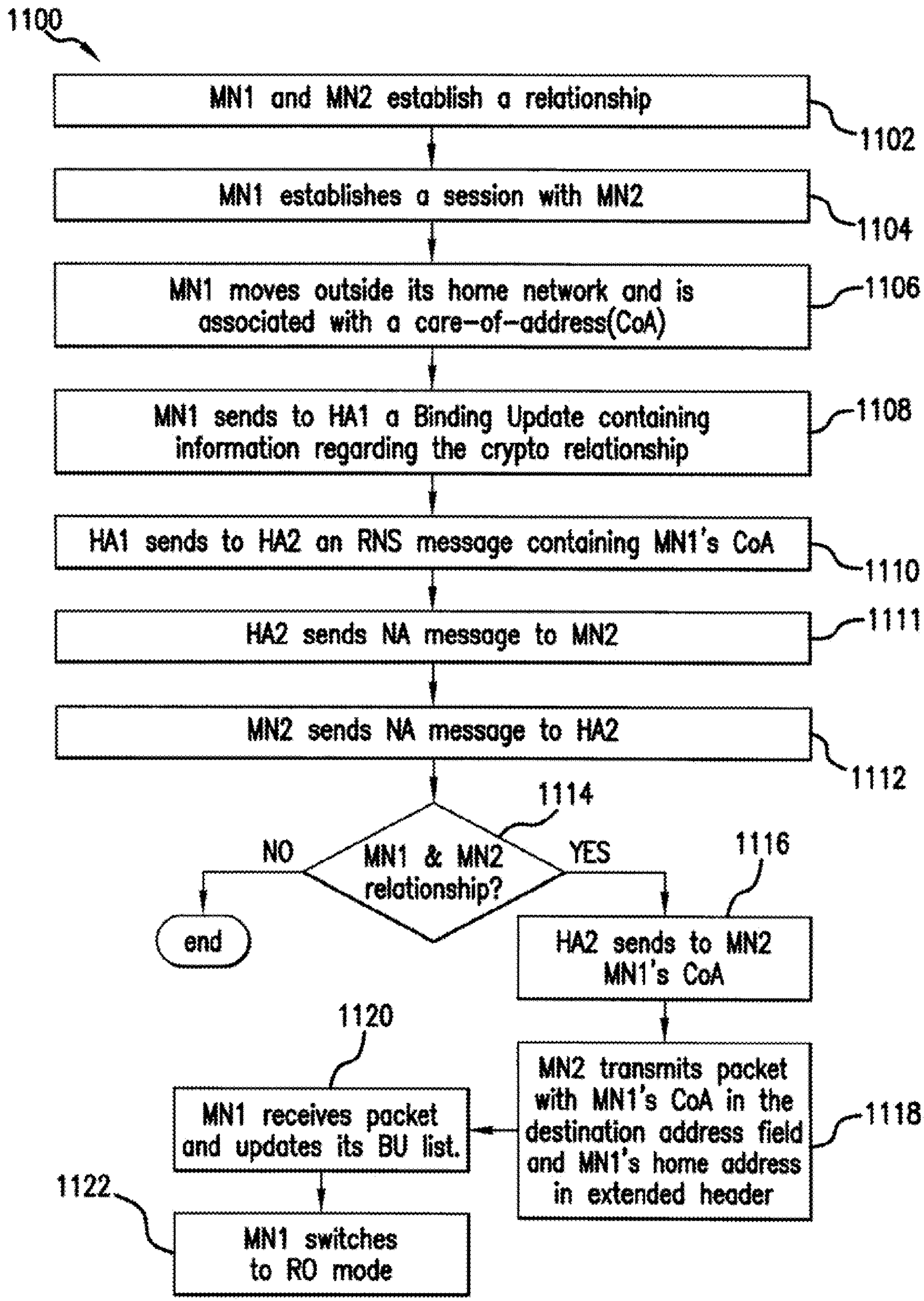
1100
MN1 and MN2 establish a relationship
1102
MN1 establishes a session with MN2
1104
MN1 moves outside its home network and is associated with a care-of-address(CoA)
1106
MN1 sends to HA1 a Binding Update containing information regarding the crypto relationship
1108
HA1 sends to HA2 an RNS message containing MN1's CoA
1110
HA2 sends NA message to MN2
1111
MN2 sends NA message to HA2
1112
1114
MN1 & MN2 relationship?
NO
YES
end
1116
HA2 sends to MN2 MN1's CoA
MN2 transmits packet with MN1's CoA in the destination address field and MN1's home address in extended header
1118
1120
MN1 receives packet and updates its BU list.
1122
MN1 switches to RO mode

FIG. 11

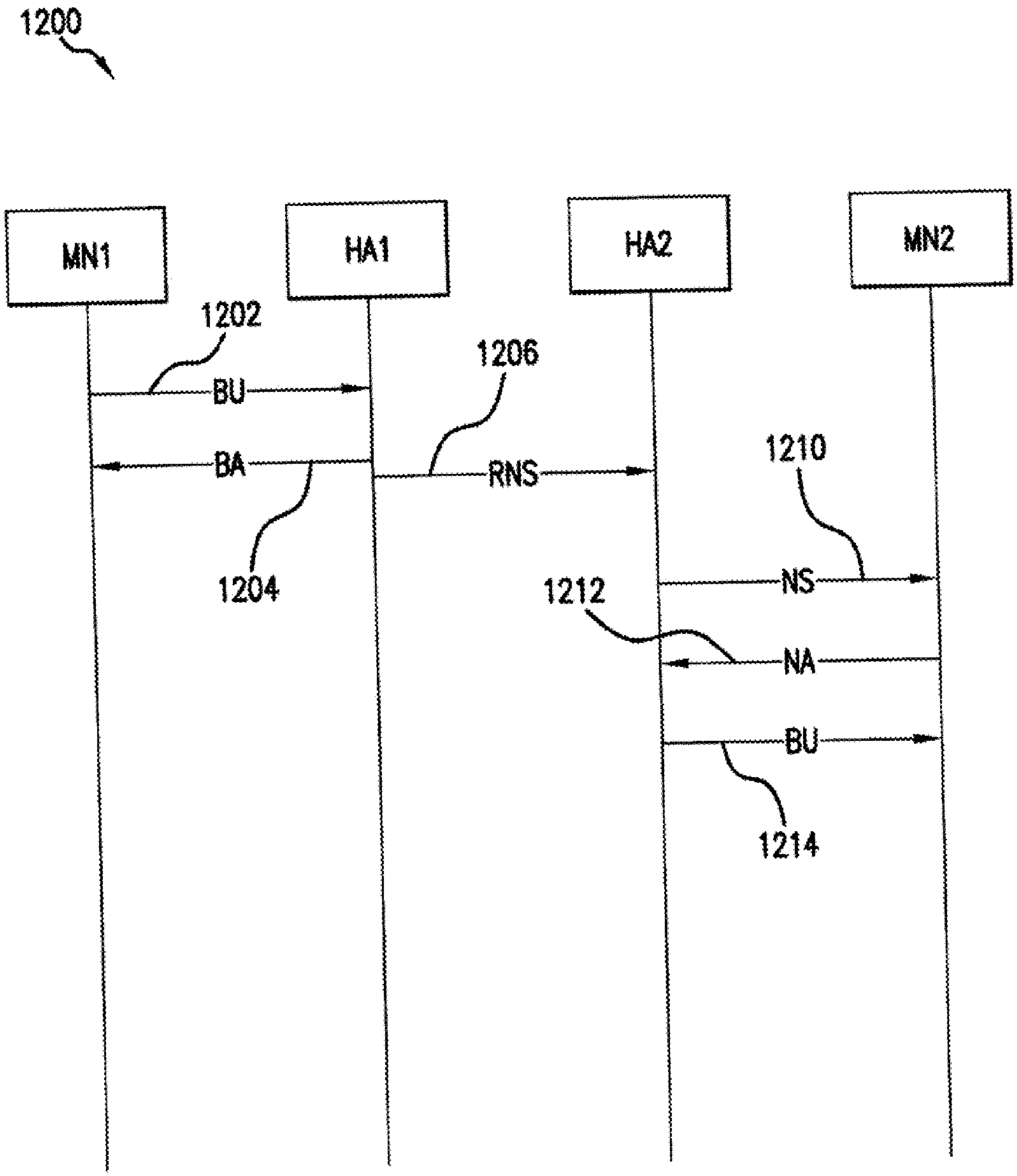
1200
MN1
HA1
HA2
MN2
1202
BU
1206
BA
RNS
1210
1204
NS
1212
NA
BU
1214

FIG.12

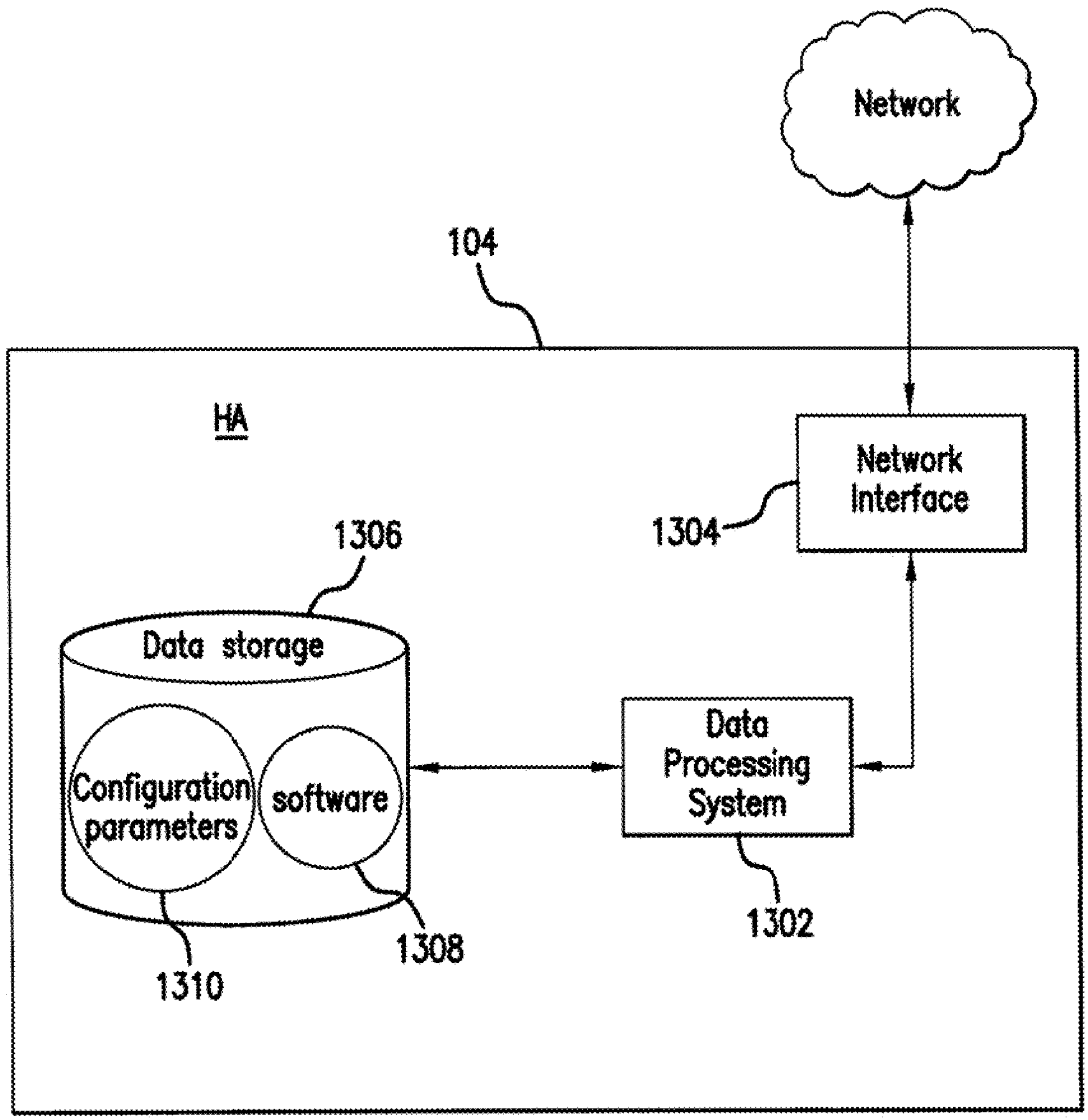
Network
104
HA
Network Interface
1304
1306
Data storage
Data Processing System
Configuration parameters
software
1302
1308
1310

FIG. 13

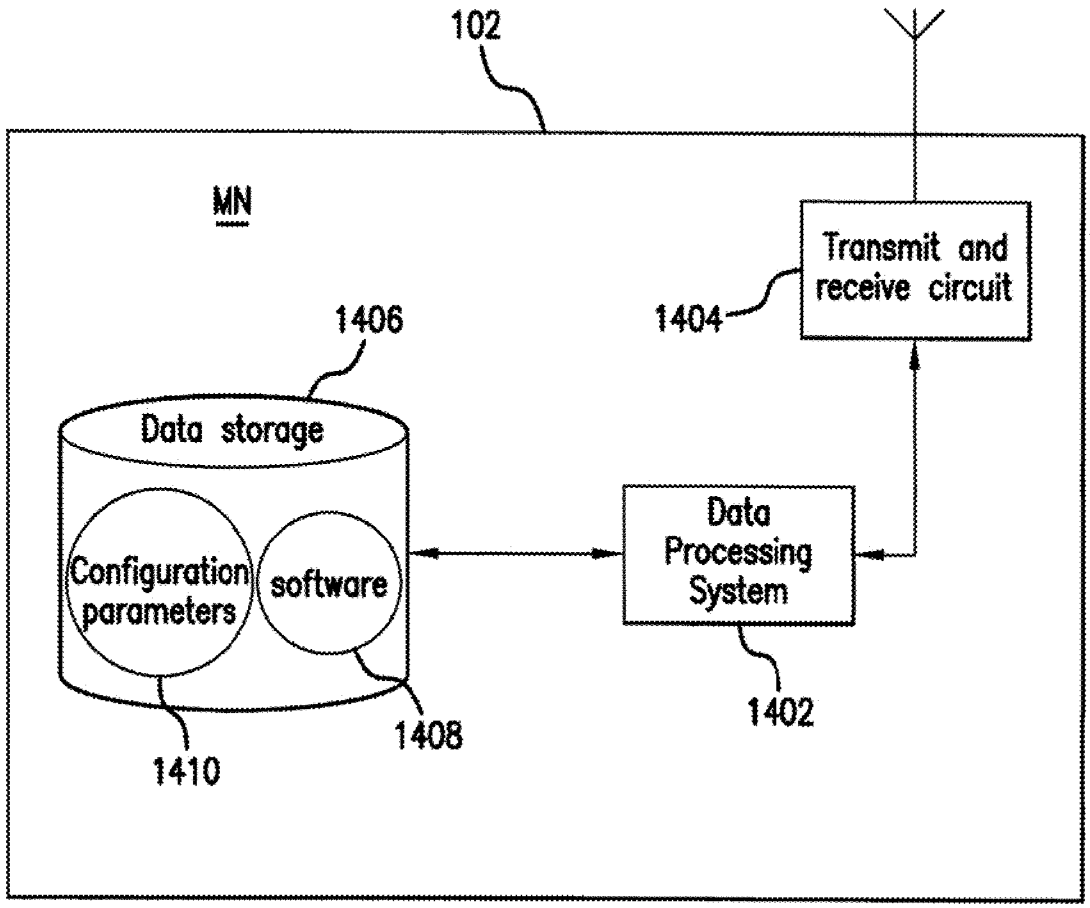
102
MN
Transmit and receive circuit
1404
1406
Data storage
Configuration parameters
software
Data Processing System
1402
1408
1410

FIG. 14

METHODS AND SYSTEMS FOR MOBILE IP ROUTE OPTIMIZATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent App. No. 61/224,610, filed on Jul. 10, 2009, and U.S. Provisional Patent App. No. 61/221,219, filed on Jun. 29, 2009. The above identified applications are incorporated by reference herein.

TECHNICAL FIELD

The present invention relates to the field of communications, and more particularly, to an enhancement for mobile IP route optimization.

BACKGROUND

Request for Comment (RFC) 3775, which is incorporated by reference herein, specifies a protocol which allows mobile nodes to remain reachable while moving around in the IPv6 Internet. Without specific support for mobility in IPv6, packets destined to a mobile node would not be able to reach the node while it is away from its home link. Mobility support is particularly important, as mobile computers are likely to account for at least a substantial fraction of the population of the Internet during the lifetime of IPv6.

The protocol defined in RFC 3775, which is known as Mobile IPv6, allows a mobile node to move from a home link to another link without changing the mobile node's "home address" (HoA). Packets may be routed to the mobile node using this address regardless of the mobile node's current point of attachment to the Internet. Accordingly, a mobile node is always expected to be reachable at its home address, whether it is currently attached to its home link or is away from home. The "home address" is an IP address assigned to the mobile node within its home subnet prefix on its home link. While a mobile node is at home, packets addressed to its home address are routed to the mobile node's home link, using conventional Internet routing mechanisms.

While a mobile node is attached to some foreign link away from home, it is also addressable at one or more "care-of addresses." A care-of address ("CoA") is an IP address associated with a mobile node that has the subnet prefix of a particular foreign link. The mobile node can acquire its care-of address through conventional IPv6 mechanisms, such as stateless or stateful auto-configuration. As long as the mobile node stays in this location, packets addressed to this care-of address will be routed to the mobile node.

The association between a mobile node's home address and care-of address is known as a "binding" for the mobile node. While away from home, a mobile node registers its primary care-of address with a "home agent" (e.g., a router or other node) on its home link. The mobile node performs this binding registration by sending a "Binding Update" message to the home agent. The home agent may reply to the mobile node by returning a "Binding Acknowledgement" message.

Any node communicating with a mobile node is referred to in this document as a "correspondent node", and may itself be either a stationary node or a mobile node.

When a mobile node is away from its home (i.e., connected to a foreign link), there are two possible modes for communications between the mobile node and a correspondent node. The first mode is referred to as the "bidirectional tunneling" mode. In the bidirectional tunneling mode, packets from the correspondent node to the mobile node are routed to the mobile node's home agent and then tunneled by the home agent to the mobile node. Similarly, packets from the mobile node to the correspondent node are tunneled from the mobile node to the home agent ("reverse tunneled") and then routed normally from the home agent to the correspondent node.

The second mode is referred to as the "route optimization" (RO) mode. In the route optimization mode, packets from the correspondent node to the mobile node can be routed directly to the care-of address of the mobile node. Routing packets directly to the mobile node's care-of address allows the shortest communications path to be used. It also may reduce congestion at the mobile node's home agent and home link. When routing packets directly to the mobile node, the correspondent node sets the Destination Address in the IPv6 header to the care-of address of the mobile node. A new type of IPv6 routing header is also added to the packet to carry the mobile nodes home address. Similarly, the mobile node sets the Source Address in the packet's IPv6 header to its current care-of addresses. The mobile node adds a new IPv6 "Home Address" destination option to carry its home address. The inclusion of home addresses in these packets makes the use of the care-of address transparent at the transport layer.

In order for a mobile node and a corresponding node to enter the RO mode, the correspondent node must have an association between the mobile node's home address and CoA and the mobile node and corresponding node must perform a "return routability" (RR) procedure. The RR procedure consists of exchanging four mobility signaling messages between the mobile node (MN) and correspondent node (CN) in order to test the MN's reachability on the claimed care-of address (CoA) and its home address and to generate a shared secret between the two nodes which is then used to authenticate a binding update (BU) and binding acknowledgment (BA) messages. It follows that successfully entering the RO mode requires in total six mobility messages, and, if we take into consideration that the MN needs first to update its home agent (HA) prior to triggering the RR procedure, then the total number of signaling messages would reach eight.

It becomes clear from the above that exchanging eight signaling messages each time the MN and a CN enter the RO mode may incur a significant data packet loss and/or delay. A further drawback is that the MN must repeat the RR procedure every 420 seconds due to security concerns. Furthermore, if the MN is having multiple sessions with different CNs then it has to repeat the RR which each CN, which in turn may severely impact the MN's power consumption.

SUMMARY

An objective of the invention is to overcome at least some of the above described RO mode disadvantages. In one aspect, this is achieved by providing an improved procedure for entering the RO mode that requires fewer signaling messages than the conventional RO mode procedures. Because fewer signaling messages are used, handoff latency decreases as well as mobile node power consumption.

Accordingly, in one aspect, the present invention provides a method for route optimization that does not require a return routability procedure. In one embodiment, the method begins with a mobile node's home agent (HA) receiving an update message transmitted from the mobile node. This update message includes a care-of-address (CoA) associated with the mobile node. In response to receiving the update message from the mobile node, the home agent binds the CoA associated with the mobile node with a home address (HoA) assigned to the mobile node. After receiving the update message, the home agent transmits a second update message to: (a) a correspondent node or (b) the correspondent node's home agent. The update message transmitted from the home agent includes the CoA associated with the mobile node and the HoA assigned to the mobile node. In this manner, a correspondent node can obtain the mobile node's CoA without the mobile node and the correspondent node having to perform the RR procedure.

In some embodiments, the correspondent node is a mobile node and the correspondent node has the same home agent as the first recited mobile node (MN). In such an embodiment, the method may also include the step of receiving, at the home agent, an update message transmitted from the correspondent node. This update message includes a CoA associated with the correspondent node. In response to receiving this update message, the home agent binds the CoA associated with the correspondent node with a HoA assigned to the correspondent node (CN). Preferably, the home agent does not transmit the second recited update message until after it receives the update message transmitted from the CN.

In some embodiments, the home agent (HA) determines whether there is a relationship between the MN and the CN after receiving the update message transmitted from the CN. In response to determining that there is a relationship between the MN and CN, the HA transmits to the MN the CoA associated with the CN and transmits to the CN the CoA associated with the MN. In some embodiments, the step of determining whether there is a relationship between the MN and the CN comprises determining whether there is a cryptographic relationship between the MN and the CN.

In some embodiments, the update message transmitted from the MN comprises a modifier value obtained from the CN and an address generated by the CN. The modifier value may be calculated by the CN by hashing a public key belonging to the MN with a random number. The update message transmitted from the CN may include a modifier value obtained from the MN and an address generated by the MN. The modifier value may be calculated by the MN by hashing a public key belonging to the CN with a random number.

In other embodiments, the CN is a mobile node but has a different HA than the first recited mobile node and the second recited update message is transmitted from the MN's HA to the CN's HA. In this embodiments, the method may also include receiving at the MN's HA a message comprising a CoA associated with the CN, wherein the message including the CoA associated with the CN was transmitted to the MN's HA from the CN's HA. In some embodiments, the MN's HA transmits to the MN a message comprising the CoA associated with the CN in response to receiving the message containing the CoA associated with the CN. In response to receiving the message from the MN's HA, the MN may add to its binding update list a record comprising the CoA associated with the CN.

In some embodiments, the HA, prior to transmitting the update message to the CN, transmits to the CN a message (e.g., a Neighbor Solicitation message). In response, the CN transmits a message back to the HA. Preferably, at least some of the information included in the message sent back to the HA from the CN depends on whether the CN has a relationship with the MN. The HA, upon receiving the message from the CN, uses information contained in the message to determine whether there is a trusted relationship between the MN and the CN. The HA is configured such that the HA will transmit the update message to the CN if and only if the HA determines that there is a trusted relationship between the MN and the CN. The information contained in the message transmitted from the CN to the HA in response to the solicitation message may include (i) parameters associated with the mobile node (e.g., an encrypted shared secret, the MN's public key, information signed using the MN's private key) and (ii) a secret that is used by the HA to encrypt information included in the update message transmitted from the HA to the CN.

In some embodiments, the mobile node has a home link, the correspondent node is a node with which the mobile node is communicating, and the home agent comprises a router on the mobile node's home link. After the mobile node connects to a foreign link and provides a CoA to the router, the router may (a) intercept packets on the home link destined to the mobile node's home address, and tunnel the intercepted packets to the mobile node's CoA.

In another aspect, the present invention provides an apparatus for facilitating mobile IP route optimization (RO). In some embodiments, the apparatus includes a network interface operable to receive from a mobile node an update message comprising a care-of-address (CoA) associated with the mobile node. The apparatus also includes a data processing system configured to (1) bind the CoA associated with the mobile node with a home address (HoA) assigned to the mobile node in response to receiving the update message and (2) transmit to (i) a correspondent node or (ii) the correspondent node's home agent a second update message comprising the CoA associated with the mobile node and the home address assigned to the mobile node after receiving the first update message. In this manner, the apparatus facilitates mobile IP route optimization by informing the correspondent node of the mobile node's CoA.

The above and other aspects and embodiments are described below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and form part of the specification, illustrate various embodiments of the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the pertinent art to make and use the invention. In the drawings, like reference numbers indicate identical or functionally similar elements.

FIG. **1** illustrates a MN in communicate with a CN while the MN is connected to an internet via its home link.

FIG. **2** illustrates the MN in communicate with the CN while the MN is connected to the internet via a foreign link.

FIG. **3** is a flow chart illustrating a process, according to a first embodiment of the invention, for performing an RO procedure.

FIG. **4** is a message flow diagram illustrating the RO procedure of FIG. **3**.

FIG. **5** is a flow chart illustrating a process, according to a second embodiment of the invention, for performing an RO procedure.

FIG. **6** is a message flow diagram illustrating the RO procedure of FIG. **5**.

FIG. **7** is a flow chart illustrating a process, according to a third embodiment of the invention, for performing an RO procedure.

FIG. **8** is a message flow diagram illustrating the RO procedure of FIG. **7**.

FIG. **9** is a flow chart illustrating a process, according to a fourth embodiment of the invention, for performing an RO procedure.

FIG. **10** is a message flow diagram illustrating the RO procedure of FIG. **9**.

FIG. **11** is a flow chart illustrating a process, according to a fifth embodiment of the invention, for performing an RO procedure.

FIG. **12** is a message flow diagram illustrating the RO procedure of FIG. **11**.

FIG. **13** is a functional block diagram of a home agent according to some embodiments of the invention.

FIG. **14** is a functional block diagram of a mobile node according to some embodiments of the invention.

DETAILED DESCRIPTION

Referring now to FIG. **1**, FIG. **1** illustrates a communication system **100**. System **100** includes a mobile node (MN) **102**, a home network **110** (a.k.a, "home link"), a home agent **104**, and a foreign network (a.k.a, "foreign link") **112**. To illustrate the various embodiments of the invention, we shall assume MN **102** has established a session (e.g., a TCP session or other session) with a correspondent node (CN) **106**. We shall also assume that, as shown in FIG. **2**, MN **102** moves away from its home network **110** without ending the session established with CN **106**. That is, while the session with CN **106** is ongoing, MN **102** attaches to a foreign network and is assigned a care-of-address (CoA).

As discussed above, when MN **102** is away from its home, there are at least two possible modes in which MN **102** may communicate with CN **106**: (1) the bidirectional tunneling mode and (2) the RO mode. As also discussed above, there are advantages for MN **102** and CN **106** to communicate in the RO mode. For example, when MN **102** and CN **106** communicate using the RO mode, packets from CN **106** to MN **102** can be routed directly to the CoA of the mobile node. Routing packets directly to the mobile node's CoA allows the shortest communications path to be used and reduces congestion at the mobile node's home agent and home link. Because the RO mode enables a more efficient data packet exchange than the bidirectional tunneling, the RO mode should be used whenever possible unless the mobile node is not interested in disclosing its topological location, i.e., care-of address, to the CN (e.g., for privacy reasons).

Referring now to FIG. **3**, FIG. **3** is a flow chart illustrating a process **300**, according to a first embodiment, for enabling MN **102** and CN **106** to enter (i.e., "switch on") the RO mode using fewer signaling messages than is required by the return routability (RR) procedure described in RFC 3775. Being able to enter the RO mode using fewer signaling message has several advantages: For example, it results in a lower handoff latency, thereby increasing communication efficiency. It also results in an improved power efficiency in the mobile node.

Process **300** assumes that CN **106** is a mobile node using the same HA (or cluster) as MN **102**. For simplicity, MN **102** shall be referred to as MN**1** and CN **106** shall be referred to as MN**2**. Process **300** may begin in step **302**, where MN**1** and MN**2** each (a) auto-configure their IPv6 home address using the "cryptographically generated addresses (CGA)" technique (see RFC 3792, March 2005) and (b) establish a mutual relationship with the other. This mutual relationship is referred to as a "trusted relationship" or "symbiotic relationship." Establishing the trusted relationship can be achieved using the "Secure Neighbor Discovery" protocol (see RFC 3971, March 2005). Additionally, other methods for establishing a relationship are known in the art (see e.g., WO2009065923, having an international filing date of 21 Nov. 2008, which publication is incorporated by reference herein). In some embodiments, the trusted relationship between MN**1** and MN**2** is of a cryptographic nature and may be established as a consequence of a mutual social relationship between the respective owners of MN**1** and MN**2**. In some embodiments, establishing a trusted relationship between MN**1** and MN**2** requires MN**1** to establish a unidirectional relationship with MN**2** and requires MN**2** to establish a unidirectional relationship with MN**1**. In some embodiments, when MN**2** establishes a unidirectional relationship with MN**1**, MN**2** receives MN**1**'s public key and generates a 128-bit modifier from hashing MN**1**'s public key together with a 128-bit random number (RAN) (Modifier=First [128, SHA-2(PK(MN1)|RAN)]). MN**2** then confidentially notifies MN**1** about the 128 bit modifier. Likewise, when MN**1** establishes a unidirectional relationship with MN**2**, MN**1** receives MN**2**'s public key and generates a 128-bit modifier from hashing MN**2**'s public key together with a 128-bit random number (RAN). MN**1** then confidentially notifies MN**2** about the 128 bit modifier.

In step **304**, MN**1** establishes a session (e.g., a TCP session) with MN**2** (or vice-versa). In step **306**, MN**1** moves outside its home network and is associated with and obtains a CoA. In step **308**, MN**1** sends to HA **104** a Binding Update (BU) message **402** (see the message flow diagram **400** shown in FIG. **4**). As used herein, a BU message is a message containing a "Mobility Header" (defined in section 6.1 of RFC 3775) where the MH type field of the Mobility Header is set to a value of 5. The BU message **402** transmitted in step **308** includes (a) the CoA obtained my MN**1** in step **306** and (b) information disclosing the relationship between MN**1** and MN**2**. This information is referred to as "proof of relationship" information. The proof of relationship information that is contained in BU message **402** may include: (a) information identifying MN**2** (e.g., an address generated by MN**2**), (b) MN**2**'s public key, and (c) a shared secret (e.g., the 128 bit modifier received from MN**2**). Preferably, for security, BU message **402** is transmitted to HA **104** using an IPsec tunnel established between MN**1** and HA **104**.

In step **310**, HA **104** associates the CoA included in message **402** with MN**1**'s home address (e.g., HA **104** creates a Binding Cache entry), stores the proof of relationship information, and sends an acknowledgement message **404** (see FIG. **4**) to MN**1**. The proof of relationship information may be stored in the Binding Cache entry or otherwise associated with MN**1**'s home address and/or CoA. Message **404** may be a Binding Acknowledgment (BA) message (see RFC 3775).

In step **312**, MN**2** moves outside its home network and obtains a CoA. In step **314**, MN**2** sends to HA **104** a Binding Update (BU) message **406** (see FIG. **4**). The BU message **406** transmitted in step **314** includes (a) the CoA obtained by MN**2** in step **312** and (b) information disclosing the relationship between MN**2** and MN**1**. This information is referred to as "proof of relationship" information. The relationship information that is contained in BU message **406** may include: (a) information identifying MN**1** (e.g., a home address generated by MN**1**), (b) MN**1**'s public key, and (c) the 128 bit modifier received from MN**1**. Preferably, for security, BU message **406** is transmitted to HA **104** using an IPsec tunnel established between MN**2** and HA **104**.

In step **316**, HA **104** determines, based on the information in BU messages **402** and **406**, whether MN**1** and MN**2** have a trusted relationship. For example, in some embodiments, in response to receiving and validating BU message **406**, which message indicates that MN**2** asserts to have a trusted relationship with MN**1**, HA **104** retrieves the proof of relationship information stored in step **310** to determine whether MN**1** also asserts that it has a relationship with MN**2**. In this way, HA **104** can determine whether there is a trusted relationship between MN**1** and MN**2** (i.e., HA **104** can determine that MN**1** asserts to have a relationship with MN**2** and MN**2** asserts to have a relationship with MN1). If HA 104 determines, that MN1 and MN2 do not have a trusted relationship, then process 300 proceeds to step 318, otherwise process 300 proceeds to step 320. In step 318, HA 104 may send to MN2 a conventional BA message (i.e., a BA message that does not include MN1's CoA).

In step 320, HA 104 sends to MN2 a BA message 408 that includes MN1's CoA. Message 408 may also include information that notifies MN2 that HA 104 will send (or has sent) MN2's CoA to MN1. This information can be encoded in a single bit referred to as a "buddy" bit. In response to message 408, MN2 may create a Binding Cache entry (i.e., store information associating MN1's HoA with MN1's CoA) and may update its Binding Update list to indicate that MN1 has received (or will soon receive) a "binding update" concerning MN2's CoA.

At the same time that message 408 is transmitted, HA 104 sends a message 410 to MN1 (step 322). Message 410 includes MN2's CoA. Message 410 may be referred to as a "Neighbor Binding Update (NBU)" message. In response to receiving NBU message 410, MN1 may send to HA 104 a Neighbor Binding Ack (NBA) message 412. In order to increase the overall performance, HA 104 can send multiple copies of the NBU message 410 until it receives the NBA message 412. Also, in response to message 410, MN1 may create a Binding Cache entry (i.e., store information associating MN2's HoA with MN2's CoA) and may update its Binding Update list to indicate that MN2 has received a "binding update" concerning MN1's CoA.

In step 324, MN1 and MN2 can switch to RO mode because each has the other's CoA.

In this manner, the RO mode can be entered without MN1 having to send any mobility message to MN2 and vice-versa. That is, the inclusion of MN 1's CoA in BA message 408 together with sending the NBU message 410 to MN1 allow both mobile nodes MN1 and MN2 to quickly learn each other's current topological location from a trusted source and to create the necessary binding in order to redirect their data packets on the optimized path. This produces the following advantages: (1) the return routability (RR) procedure is entirely removed which means the number of signaling messages is reduced to zero and the two MNs won't need to share secrets and refresh them (thus helping increase the service provider's available bandwidth instead of being consumed by signaling messages); (2) removes the need to upgrade CNs to understand RR signaling, as such, it can be seen as a first step towards deploying the RO mode between nodes belonging to the same home network with zero signaling on the direct path; (3) significantly reduces IP handoff latency; and (4) reduces mobile node power consumption.

It should be noted that steps 314-324 may be repeated whenever MN2 obtains a new CoA. Additionally, process 300 can be extended to include multiple mobile nodes. That is, MN2 may have a trusted relationship not only with MN1, but also with MN3, in which case HA 104, in step 320, will send an NBU message to each mobile with which MN2 has a trusted relationship. Process 300 also applies to the case where MN1 or MN2 has multiple interfaces (e.g., multiple home addresses). In this case, HA 104 can also notify the mobile node about using a CoA which is configured on another interface attached to the mobile node's device and/or about a CoA configured on another interface attached to the other endpoint's device.

Referring now to FIG. 5, FIG. 5 is a flow chart illustrating a process 500, according to a second embodiment, for enabling MN 102 and CN 106 to enter the RO mode using few mobility messages.

Process 500 assumes that CN 106 is a mobile node using a different HA (or cluster) than MN 102. For simplicity, MN 102 shall be referred to as MN1, CN 106 shall be referred to as MN2, MN1's home agent shall be referred to as HA1, and MN2's home agent shall be referred to as HA2. Process 500 also assumes that HA1 has HA2's IP address and well as HA2's advertised prefixes) and public key(s) and vice-versa. For example, HA1 and HA2 may each have a list of other HAs' and their corresponding IP addresses, prefixes and keys. Preferably, for security purposes, HA1 and HA2 can set up and IPsec tunnel between them.

Process 500 may begin in step 502, where MN1 and MN2 each (a) auto-configure their IPv6 home address using the CGA technique and (b) establish a relationship with the other, as described above with reference to process 300.

In step 504, MN1 establishes a session with MN2 (or vice-versa). In step 506, MN1 moves outside its home network and is associated with and obtains a CoA.

In step 508, MN1 sends to HA1 a BU message 602 (see the message flow diagram 600 shown in FIG. 6). The BU message 602 transmitted in step 508 includes (a) the CoA obtained by MN1 in step 506 and (b) information disclosing the relationship between MN1 and MN2. This information is referred to as "proof of relationship" information, examples of which are provided above in the description of process 300.

In step 510, in response to message 602, HA1 creates a binding cache entry for MN1, sends to MN1 a BA message 604 (see FIG. 6), uses at least some of the proof of relationship information (e.g., MN2's IP address) to obtain HA2's corresponding parameters (e.g., HA2's IP address and public key) and sends to HA2 an update message 606 (a.k.a., a "RO Neighbor Solicitation (RNS)" message). Message 606 includes MN1's CoA and information indicating that MN1 has disclosed in message 602 that MN1 has a relationship with MN2. Thus, message 606 may include information identifying MN1 (e.g., MN1' home address) and may also include at least some of the proof of relationship information included in message 602 (e.g., MN2's home address). Assuming that MN2 is still attached to its home network at the time message 606 is received, HA2 simply stores information included in message 606 for later use, as described below. Additionally, HA2 may send to HA1 a RO Neighbor Present (RNP) message 608 (see FIG. 6). Message 608 is used to inform HA1 of MN2's status.

In step 512, MN2 moves outside its home network and obtains a CoA. In step 514, MN2 sends to HA2 a BU message 610 (see FIG. 6). The BU message 610 transmitted in step 514 includes (a) the CoA obtained by MN2 in step 512 and (b) information disclosing the relationship between MN2 and MN1 (e.g., MN1's IP address).

In step 516, HA2 determines, based on the information in BU message 610 and RNS message 606, whether MN1 and MN2 have a trusted relationship. For example, in step 516, in response to receiving BU message 610, which may include MN1's home address, HA2 uses MN1's home address to determine whether HA2 has received from HA1 an RNS message indicating that MN1 has disclosed a relationship with MN2 and, if such an RNS message was received from HA1, then HA2 retrieves MN1's CoA, which was included in the RNS message.

If HA 104 determines, that MN1 and MN2 do not have a trusted relationship, then process 500 proceeds to step 518, otherwise process 500 proceeds to step 520. In step 518, HA2 may send to MN2 a conventional BA message 613 (i.e., a BA message 613 that does not include MN1's CoA).

In step 520, HA2 sends to HA1 MN2's CoA. For example, in step 520, HA2 may send to HA1 an RO Neighbor Update

(RNU) message **614** that includes MN**2**'s CoA. In step **522**, in response to message **614**, HA**1** sends to MN**1** MN**2**'s CoA. For example, in step **522**, HA**1** sends to MN**1** a NBU message **616** containing MN**2**'s CoA. In response to message **616**, MN**1** may create a Binding Cache entry (i.e., store information associating MN**2**'s HoA with MN**2**'s CoA) and may update its Binding Update list to indicate that MN**2** has received (or will soon receive) a "binding update" message concerning MN**1**'s CoA.

In step **524**, HA**2** sends to MN**2** a BA message **613'** that includes MN**1**'s CoA. Message **613'** may also include information that notifies MN**2** that HA**2** will send (or has sent) MN**2**'s CoA to HA**1**. In some embodiments, after HA**2** sends the RNU **614** to HA**1**, HA**2** waits for an acknowledgement from HA**1** before performing step **524**. In response to message **613'**, MN**2** should create a Binding Cache entry (i.e., store information associating MN**1**'s HoA with MN**1**'s CoA) and should update its Binding Update list to indicate that MN**1** has received a "binding update" concerning MN**2**'s CoA.

In response to receiving NBU message **616**, MN**1** may send to HA**1** a Neighbor Binding Ack (NBA) message **618**. In step **526**, MN**1** and MN**2** can both switch to RO mode because each has the other's CoA.

Referring now to FIG. **7**, FIG. **7** is a flow chart illustrating a process **700**, according to a third embodiment, for enabling MN **102** and CN **106** to enter the RO mode using few mobility messages. Process **700** may begin in step **702**, where MN **102** and CN **106** each establish a relationship with the other (e.g., as described above with reference to process **300**). In step **704**, MN **102** establishes a session with CN **106** (or vice-versa). In step **706**, MN **102** moves outside its home network and obtains a CoA. In step **708**, MN **102** sends to HA **104** a BU message **802** (see the message flow diagram **800** shown in FIG. **8**). The BU message **802** transmitted in step **708** includes (a) the CoA obtained by MN **102** in step **706** and (b) information disclosing the relationship between MN **102** and CN **106**. This information is referred to as "proof of relationship" information, examples of which are provided above in the description of process **300**.

In step **710**, in response to message **802**, HA **104** creates a binding cache entry for MN **102**, sends to MN **102** a BA message **804** (see FIG. **8**), and sends a message **806** to CN **106**. Message **806** seeks confirmation from CN **106** that CN **106** and MN **102** have a trusted relationship. Message **806** may be a "Neighbor Discovery" protocol message (see RFC 2461) that is used to convey MN **102**'s HoA and public key to CN **106**. For this purpose, two parameters may be added in two new options in the "neighbor solicitation (NS)" message. Preferably, the Neighbor solicitation message is be signed by HA **104**. The most convenient way to implement the security requirement is to use "Secure Neighbor Discovery (SeND)" (see RFC 3971).

If CN **106** has a relationship with MN **102**, then it should reply to HA **104** by disclosing parameters related to the "proof-of relationship" with MN **102**. These parameters may be carried in a "Neighbor Advertisement (NA)" message **808** which is sent back to HA **104**. Preferably, the "proof-of-relationship" parameters are encrypted. For this purpose, CN **106** may encrypt these parameters with HA **104**'s public key before signing the entire message. If, however, CN **106** is not interested in disclosing the proof of relationship parameters or does not have such a relationship, then CN **106** should return a simple NA message to HA. In either case, an NA message **808** (or other message) is returned to HA **104** in response to message **806** (step **712**).

In step **714**, HA **104** determines, based on the response from CN **106** (or lack thereof) to message **806**, whether CN **106** and MN **102** have a relationship. If HA **104** determines, that MN **102** and CN **106** do not have a relationship, then process **700** may end, otherwise process **700** proceeds to step **716**.

In step **716**, HA **104** sends to CN **106** an update message **810** (e.g., Binding Update message) containing, among other things, MN **102**'s HoA and current CoA. CN **106** may include a secret in message **808** that enables HA **104** to encrypt and authenticate update message **810**. In response to message **810**, CN **106** creates a Binding Cache entry that associates MN **102**'s HoA with MN **102**'s CoA. In step **718**, CN **106** transmits an IPv6 packet with MN **102**'s CoA in the destination address field and MN **102**'s HoA in an extended header of the packet (e.g., in a type **2** routing header). This packet is routed to MN **102**. In step **720**, MN **102** receives the packet and, in response to receiving the packet, updates its Binding Update list to indicate that CN **106** has received an "update" concerning MN **102**'s CoA. In step **722**, MN **102** switches to the RO mode.

Referring now to FIG. **9**, FIG. **9** is a flow chart illustrating a process **900**, according to a fourth embodiment, for enabling MN **102** and CN **106** to enter the RO mode using few mobility messages. Process **900** may begin in step **902**, where MN **102** establishes a session with CN **106** (or vice-versa). In step **904**, MN **102** moves outside its home network and is associated with and obtains a CoA. In step **906**, MN **102** sends to HA **104** a BU message **1002** (see the message flow diagram **1000** shown in FIG. **10**). The BU message **1002** transmitted in step **908** includes (a) the CoA obtained by MN **102** in step **906**.

In step **908**, in response to message **1002**, HA **104** creates a binding cache entry for MN **102**, sends to MN **102** a BA message **1004** (see FIG. **10**), and sends to CN **106** an update message **1006** (e.g., a Binding Update message) containing, among other things, MN **102**'s HoA and current CoA. In response to message **1006**, CN **106** creates a Binding Cache entry that associates MN **102**'s HoA with MN **102**'s CoA. In step **910**, CN **106** transmits an IPv6 packet with MN **102**'s CoA in the destination address field and MN **102**'s HoA in an extended header of the packet (e.g., in a type **2** routing header). This packet is routed to MN **102**. In step **912**, MN **102** receives the packet and, in response to receiving the packet, updates its Binding Update list to indicate that CN **106** has received an "update" concerning MN **102**'s CoA. In step **914**, MN **102** switches to the RO mode.

Referring now to FIG. **11**, FIG. **11** is a flow chart illustrating a process **1100**, according to a fifth embodiment, for enabling MN **102** and CN **106** to enter the RO mode using few mobility messages. Process **1100** assumes that CN **106** is a mobile node using a different HA (or cluster) than MN **102**. For simplicity, MN **102** shall be referred to as MN**1**, CN **106** shall be referred to as MN**2**, MN**1**'s home agent shall be referred to as HA**1**, and MN**2**'s home agent shall be referred to as HA**2**. Process **1100** also assumes that HA**1** has HA**2**'s IP address as well as HA**2**'s advertised prefixes) and public key(s) and vice-versa. For example, HA**1** and HA**2** may each have a list of other HAs' and their corresponding IP addresses, prefixes and keys. Preferably, for security purposes, HA**1** and HA**2** can set up and IPsec tunnel between them.

Process **1100** may begin in step **1102**, where MN**1** and MN**2** each (a) auto-configure their IPv6 home address using the CGA technique and (b) establish a relationship with the other, as described above with reference to process **300**.

In step **1104**, MN**1** establishes a session with MN**2** (or vice-versa). In step **1106**, MN**1** moves outside its home network and is associated with and obtains a CoA.

In step **1108**, MN**1** sends to HA**1** a BU message **1202** (see the message flow diagram **1200** shown in FIG. **12**). The BU message **1202** transmitted in step **1108** includes (a) the CoA obtained by MN**1** in step **1106** and (b) information disclosing the relationship between MN**1** and MN**2**. This information is referred to as "proof of relationship" information, examples of which are provided above in the description of process **300**.

In step **1110**, in response to message **1202**, HA**1** creates a binding cache entry for MN**1**, sends to MN**1** a BA message **1204** (see FIG. **12**), uses at least some of the proof of relationship information (e.g., MN**2**'s IP address) to obtain HA**2**'s corresponding parameters (e.g., HA**2**'s IP address and public key) and sends to HA**2** an update message **1206** (a.k.a., a "RO Neighbor Solicitation (RNS)" message). Message **1206** includes MN**1**'s CoA and information indicating that MN**1** has disclosed in message **1202** that MN**1** has a relationship with MN**2**. Thus, message **1206** may include information identifying MN**1** (e.g., MN**1**' home address) and may also include at least some of the proof of relationship information included in message **1202** (e.g., MN**2**'s home address).

In step **1111**, in response to message **1206**, HA**2** sends a message **1210** to MN**2**. Message **1210** seeks confirmation from MN**2** that MN**2** and MN**1** have a trusted relationship. Message **1210** may be a "Neighbor Discovery" protocol message that is used to convey MN**1**'s HoA and public key to MN**2**.

If MN**2** has a relationship with MN**1**, then it should reply to HA**2** by disclosing parameters related to the "proof-of relationship" with MN**1**. These parameters may be carried in a "Neighbor Advertisement (NA)" message **1212** which is sent back to HA**2**. If, however, MN**2** is not interested in disclosing the proof of relationship parameters or does not have such a relationship, then MN**2** should return a simple NA message to HA**2**. In either case, an NA message **1212** (or other message) is returned to HA**2** in response to message **1210** (step **1112**).

In step **1114**, HA**2** determines, based on the response from MN**2** (or lack thereof) to message **1210**, whether MN**2** and MN**1** have a relationship. If HA**2** determines, that MN**1** and MN**2** do not have a relationship, then process **1100** may end, otherwise process **1100** proceeds to step **1116**.

In step **1116**, HA**2** sends to MN**2** an update message **1214** (e.g., Binding Update message) containing, among other things, MN**1**'s HoA and current CoA. MN**2** may include a secret in message **1212** that enables HA**2** to encrypt and authenticate update message **1214**. In response to message **1214**, MN**2** creates a Binding Cache entry that associates MN**1**'s HoA with MN**1**'s CoA. In step **1118**, MN**2** transmits an IPv6 packet with MN**1**'s CoA in the destination address field and MN**1**'s HoA in an extended header of the packet (e.g., in a type **2** routing header). This packet is routed to MN**1**. In step **1120**, MN**1** receives the packet and, in response to receiving the packet, updates its Binding Update list to indicate that MN**2** has received an "update" concerning MN**1**'s CoA. In step **1122**, MN**1** switches to the RO mode.

Referring now to FIG. **13**, FIG. **13** is a functional block diagram of HA **104** according to some embodiments of the invention. As shown, HA **104** may comprise a data processing system **1302** (e.g. one or more microprocessors, one or more integrated circuits, such as an application specific integrated circuit (ASIC), Field-programmable gate arrays (FPGAs), etc. and any combination of these), a data storage system **1306** (e.g. one or more non-volatile storage devices) and computer software **1308** stored on the storage system **1306**. Configuration parameters **1310** may also be stored in storage system **1306**. HA **104** may also include one or more network interfaces **1304** for communicating with MN **102** and CN **106**. In some embodiments, software **1308** is configured such that when processing system **1302** executes software **1308**, HA **104** performs steps described above (e.g., steps described above with reference to the flow charts shown in FIGS. **3**, **5**, **7**, **9** and/or **11**). In other embodiments, data processing system **1302** is configured to perform steps described above with reference to the flow charts without the need for software **1308**. That is, for example, data processing system may consist merely of one or more ASICs. Hence, the features of the present invention described above may be implemented in hardware and/or software.

Referring now to FIG. **14**, FIG. **14** is a functional block diagram of MN **102** according to some embodiments of the invention. As shown, MN **102** may comprise a data processing system **1402** (e.g. one or more microprocessors, one or more integrated circuits, such as an application specific integrated circuit (ASIC), Field-programmable gate arrays (FPGAs), etc. and any combination of these), a data storage system **1406** (e.g. one or more non-volatile storage devices) and computer software **1408** stored on the storage system **1406**. Configuration parameters **1410** may also be stored in storage system **1406**. MN **102** may also include a network interface **1404** for communicating with HA **104** and CN **106**. In some embodiments, software **1408** is configured such that when processing system **1402** executes software **1408**, HA **104** performs steps described above (e.g., steps described above with reference to the flow charts shown in FIGS. **3**, **5**, **7**, **9** and/or **11**). In other embodiments, data processing system **1402** is configured to perform steps described above with reference to the flow charts without the need for software **1408**. That is, for example, data processing system may consist merely of one or more ASICs. Hence, the features of the present invention described above may be implemented in hardware and/or software.

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

Additionally, while the processes described above and illustrated in the drawings are shown as a sequence of steps, this was done solely for the sake of illustration. Accordingly, it is contemplated that some steps may be added, some steps may be omitted, the order of the steps may be re-arranged, and some steps may be performed in parallel.

What is claimed is:

1. A method for route optimization that does not require a return routability procedure, the method comprising the steps of:

(a) receiving, at a home agent, a first update message transmitted from a mobile node, the first update message comprising a care-of-address (CoA) associated with the mobile node, wherein, in response to receiving the first update message, the home agent binds the CoA associated with the mobile node with a home address assigned to the mobile node; and

(b) after receiving the first update message, transmitting a second update message from the home agent to a correspondent node, the second update message comprising the CoA associated with the mobile node and the home address assigned to the mobile node;

wherein step (b) is not performed until the home agent determines there is a trusted relationship between the mobile node and the correspondent node, and wherein the trusted relationship exists if the home agent determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node, and wherein the correspondent node is a node with which the mobile node is communicating;

wherein the correspondent node is a mobile node and the correspondent node has the same home agent as the mobile node, and the method further comprises:

(c) receiving, at the home agent, a third update message transmitted from the correspondent node, the third update message comprising a CoA associated with the correspondent node, wherein, in response to receiving the third update message, the home agent binds the CoA associated with the correspondent node with a home address assigned to the correspondent node, wherein

step (b) is not performed until after the home agent receives the third update message.

2. The method of claim **1**, further comprising:

(d) after receiving the third update message, determining whether there is the trusted relationship between the mobile node and the correspondent node; and

(e) in response to determining that there is the trusted relationship between the two nodes, then transmitting to the mobile node the CoA associated with the correspondent node and transmitting to the correspondent node the CoA associated with the mobile node, wherein

steps (d) and (e) are performed by the home agent.

3. The method of claim **2**, wherein

the first update message comprises a modifier value obtained from the correspondent node and an address generated by the correspondent node, wherein the modifier value was calculated by the correspondent node by hashing a public key belonging to the mobile node with a random number, and

the third update message comprises a modifier value obtained from the mobile node and an address generated by the mobile node, wherein the modifier value was calculated by the mobile node by hashing a public key belonging to the correspondent node with a random number.

4. The method of claim **2**, wherein the home agent determines there is the trusted relationship between the mobile node and the correspondent node when the home agent determines that the mobile node asserts to have a relationship with the correspondent node and the correspondent node asserts to have a relationship with the mobile node.

5. The method of claim **1**, wherein

the mobile node has a home link;

the home agent comprises a router on the mobile node's home link, and

after the mobile node connects to a foreign link and provides the CoA to the router, the router performs the steps of: (i) intercepting packets on the home link destined to the mobile node's home address, and (ii) tunneling the intercepted packets to the mobile node's CoA.

6. A method for route optimization that does not require a return routability procedure, the method comprising the steps of:

(a) receiving, at a home agent, a first update message transmitted from a mobile node, the first update message comprising a care-of-address (CoA) associated with the mobile node, wherein, in response to receiving the first update message, the home agent binds the CoA associated with the mobile node with a home address assigned to the mobile node; and

(b) after receiving the first update message, transmitting a second update message from the home agent to: a home agent of a correspondent node, the second update message comprising the CoA associated with the mobile node and the home address assigned to the mobile node;

wherein the correspondent node is a node with which the mobile node is communicating;

wherein the correspondent node is a mobile node, the correspondent node has a different home agent than the mobile node, the second update message is transmitted from the home agent to the correspondent node's home agent, and the method further comprises:

(c) receiving at the mobile node's home agent a message comprising a CoA associated with the correspondent node, wherein the message comprising the CoA associated with the correspondent node was transmitted to the mobile node's home agent from the correspond node's home agent after the correspondent node's home agent determines there is a trusted relationship between the mobile node and the correspondent node, and wherein the trusted relationship exists if the correspondent node's home agent determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node; and

(d) in response to receiving the message containing the CoA associated with the correspondent node, transmitting, from the mobile node's home agent to the mobile node, a message comprising the CoA associated with the correspondent node.

7. The method of claim **6**, wherein, in response to receiving the message from the mobile node's home agent, the mobile node adds to its binding update list a record comprising the CoA associated with the correspondent node.

8. The method of claim **6**, wherein:

the first update message further comprises information indicating that the mobile node has a relationship with the correspondent node; and

the second update message further comprises information indicating that the mobile node has indicated that it has a relationship with the correspondent node.

9. The method of claim **8**, wherein:

the information within the first update message comprises: (i) information identifying the correspondent node; (ii) a public key of the correspondent node; and (iii) a shared secret between the mobile node and the correspondent node; and

the information within the second update message comprises the following: (i) the information identifying the correspondent node; (ii) the public key of the correspondent node; and (iii) the shared secret between the mobile node and the correspondent node.

10. A method for route optimization that does not require a return routability procedure, the method comprising the steps of:

(a) receiving, at a home agent, a first update message transmitted from a mobile node, the first update message comprising a care-of-address (CoA) associated with the mobile node, wherein, in response to receiving the first update message, the home agent binds the CoA associated with the mobile node with a home address assigned to the mobile node; and

(b) after receiving the first update message, transmitting a second update message from the home agent to a correspondent node, the second update message comprising the CoA associated with the mobile node and the home address assigned to the mobile node;

wherein step (b) is not performed until the home agent determines there is a trusted relationship between the mobile node and the correspondent node, and wherein the trusted relationship exists if the home agent determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node, and wherein the correspondent node is a node with which the mobile node is communicating;

(c) prior to step (b), transmitting a first message to the correspondent node, wherein the first message is transmitted from the home agent;

(d) receiving at the home agent a second message transmitted from the correspondent node in response to the first message;

(e) after receiving the second message, using information contained in the second message to determine whether there is the trusted relationship between the mobile node and the correspondent node; and

(f) after step (e), transmitting the second update message to the correspondent node, wherein

step (f) is performed if and only if the home agent determines in step (e) that there is the trusted relationship between the mobile node and the correspondent node.

11. The method of claim **10**, wherein

the information contained in the second message comprises encrypted parameters associated with the mobile node, and

the second message includes a secret that is used by the HA to encrypt information included in the second update message.

12. The method of claim **11**, wherein the parameters associated with the mobile node include one or more of the following parameters: the mobile node's public key and a shared secret.

13. A method for route optimization that does not require a return routability procedure, the method comprising the steps of:

(a) receiving, at a home agent, a first update message transmitted from a mobile node, the first update message comprising a care-of-address (CoA) associated with the mobile node, wherein, in response to receiving the first update message, the home agent binds the CoA associated with the mobile node with a home address assigned to the mobile node; and

(b) after receiving the first update message, transmitting a second update message from the home agent to a home agent of a correspondent node, the second update message comprising the CoA associated with the mobile node and the home address assigned to the mobile node;

wherein the correspondent node is a node with which the mobile node is communicating;

wherein the correspondent node is a mobile node, the correspondent node has a different home agent than the mobile node, the second update message is transmitted from the home agent to the correspondent node's home agent, and the method further comprises:

in response to receiving the second update message, transmitting, from the correspondent node's home agent, a solicitation message to the correspondent node;

receiving, at the correspondent node's home agent, a response to the solicitation message;

using the response to the solicitation message to determine whether the mobile node and the correspondent node have a trusted relationship, wherein the trusted relationship exists if the correspondent node's home agent determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node; and

transmitting, from the correspondent node's home agent, a third update message to the correspondent node, wherein the third update message comprises the mobile node's home address (HoA) and care-of address (CoA), wherein

the correspondent node is configured such that the correspondent node binds the mobile node's HoA and CoA in response to receiving the third update message.

14. An apparatus for facilitating mobile IP route optimization (RO), the apparatus comprising:

a network interface operable to receive a first update message transmitted from a mobile node, the first update message comprising a care-of-address (CoA) associated with the mobile node; and

a data processing system configured to (1) bind the CoA associated with the mobile node with a home address (HoA) assigned to the mobile node in response to receiving the first update message and (2) transmit to a correspondent node, a second update message comprising the CoA associated with the mobile node and the home address assigned to the mobile node after receiving the first update message;

wherein the second update message is not transmitted until the data processing system determines there is a trusted relationship between the mobile node and the correspondent node, and wherein the trusted relationship exists if the data processing system determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node, and wherein the correspondent node is a node with which the mobile node is communicating;

the data processing system is operable to receive via a network interface a third update message transmitted from the correspondent node, the third update message comprising a CoA associated with the correspondent node, wherein, the data processing system is configured such that in response to receiving the third update message to bind the CoA associated with the correspondent node with a home address assigned to the correspondent node, and

the data processing system is configured to transmit the second update message only after the data processing system receives the third update message.

15. The apparatus of claim **14**, wherein the data processing system is configured such that:

after receiving the third update message, the data processing system determines whether there is the trusted relationship between the mobile node and the correspondent node; and

in response to determining that there is the trusted relationship between the two nodes, the data processing system transmits to the mobile node the CoA associated with the correspondent node and transmits to the correspondent node the CoA associated with the mobile node.

16. The apparatus of claim **15**, wherein

the first update message comprises a modifier value obtained from the correspondent node and an address generated by the correspondent node, wherein the modifier value was calculated by the correspondent node by hashing a public key belonging to the mobile node with a random number, and

the third update message comprises a modifier value obtained from the mobile node and an address generated by the mobile node, wherein the modifier value was calculated by the mobile node by hashing a public key belonging to the correspondent node with a random number.

17. The apparatus of claim **15**, wherein the data processing system determines there is the trusted relationship between the mobile node and the correspondent node when the home agent determines that the mobile node asserts to have a relationship with the correspondent node and the correspondent node asserts to have a relationship with the mobile node.

18. The apparatus of claim **14**, wherein the apparatus is a home agent.

19. The apparatus of claim **18**, wherein the home agent is configured such that, after the mobile node connects to a foreign link and provides the CoA to the home agent, the home agent:

intercepts packets on the home link destined to the mobile node's home address, and

tunnels the intercepted packets to the mobile node's CoA.

20. An apparatus for facilitating mobile IP route optimization (RO), the apparatus comprising:

a network interface operable to receive a first update message transmitted from a mobile node, the first update message comprising a care-of-address (CoA) associated with the mobile node; and

a data processing system configured to (1) bind the CoA associated with the mobile node with a home address (HoA) assigned to the mobile node in response to receiving the first update message and (2) transmit to a correspondent node, a second update message comprising the CoA associated with the mobile node and the home address assigned to the mobile node after receiving the first update message;

wherein the second update message is not transmitted until the data processing system determines there is a trusted relationship between the mobile node and the correspondent node, and wherein the trusted relationship exists if the data processing system determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node, and wherein the correspondent node is a node with which the mobile node is communicating;

the data processing system is configured such that:

prior to transmitting the second update message to the correspondent node, the data processing system transmits a first message to the correspondent node;

after receiving a second message transmitted from the correspondent node in response to the first message, the data processing system uses information contained in the second message to determine whether there is the trusted relationship between the mobile node and the correspondent node; and

the data processing system transmits the second update message to the correspondent node if and only if the data processing system determines that there is the trusted relationship between the mobile node and the correspondent node.

21. The apparatus of claim **20**, wherein

the information contained in the second message comprises encrypted parameters associated with the mobile node, and

the second message includes a secret that is used by the data processing system to encrypt information included in the second update message.

22. The apparatus of claim **21**, wherein the parameters associated with the mobile node include one or more of the following parameters: the mobile node's public key and a shared secret.

23. A home agent for facilitating mobile IP route optimization (RO) by interacting with a correspondent node and another home agent, wherein the another home agent interacts with a mobile node, the home agent comprising:

one or more network interfaces operable to receive a first update message transmitted from the another home agent, the first update message comprising a care-of-address (CoA) associated with the mobile node and information indicating that the mobile node has indicated that it has a relationship with the correspondent node;

the one or more network interfaces operable to receive a second update message transmitted from the correspondent node, the second update message comprising a care-of-address (CoA) associated with the correspondent node, and information disclosing that the correspondent node has a relationship with the mobile node;

a data processing system operable to determine based on the first and second update messages that there is a trusted relationship between the mobile node and the correspondent node, and wherein the trusted relationship exists if the home agent determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node, and wherein the correspondent node is a node with which the mobile node is communicating.

24. The home agent of claim **23**, wherein:

the information within the first update message comprises the following: (i) information identifying the correspondent node; (ii) a public key of the correspondent node; and (iii) a shared secret between the mobile node and the correspondent node; and

the information within the second update message comprises: (i) information identifying the mobile node; (ii) a public key of the mobile node; and (iii) a shared secret between the mobile node and the correspondent node.

25. A method implemented by a home agent for facilitating mobile IP route optimization, wherein the home agent interacts with a correspondent node and another home agent, and wherein the another home agent interacts with a mobile node, the method comprising the steps of:

receiving a first update message transmitted from the another home agent, the first update message comprising a care-of-address (CoA) associated with the mobile node and information indicating that the mobile node has indicated that it has a relationship with the correspondent node;

receiving a second update message transmitted from the correspondent node, the second update message comprising a care-of-address (CoA) associated with the correspondent node and information disclosing that the correspondent node has a relationship with the mobile node; and

determining based on the first and second update messages that there is a trusted relationship between the mobile node and the correspondent node, and wherein the trusted relationship exists if the home agent determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node, and wherein the correspondent node is a node with which the mobile node is communicating.

26. The method of claim **25**, wherein:

the information within the first update message comprises the following: (i) information identifying the correspondent node; (ii) a public key of the correspondent node; and (iii) a shared secret between the mobile node and the correspondent node; and the information within the second update message comprises: (i) information identifying the mobile node; (ii) a public key of the mobile node; and (iii) a shared secret between the mobile node and the correspondent node.

27. A home agent for facilitating mobile IP route optimization (RO) by interacting with a correspondent node and another home agent, wherein the correspondent node is a mobile node, and wherein the another home agent interacts with a mobile node, the home agent comprising:

one or more network interfaces operable to receive a first update message transmitted from the another home agent, the first update message comprising a care-of-address (CoA) associated with the mobile node and information indicating that the mobile node has indicated that it has a relationship with the correspondent node;

a data processing system operable in response to receiving the first update message to transmit a solicitation message to the correspondent node, wherein the solicitation message is requesting confirmation from the correspondent node that the correspondent node and the mobile node have a trusted relationship;

the one or more network interfaces operable to receive a response to the solicitation message;

the data processing system operable in response to the solicitation message to determine whether the mobile node and the correspondent node have a trusted relationship, wherein the trusted relationship exists if the data processing system determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node; and

the one or more network interfaces operable to transmit a second update message to the correspondent node if the data processing system has determined there is the end-to-end cryptographic relationship between the mobile node and the correspondent node, wherein the second update message comprises the mobile node's home address (HoA) and care-of address (CoA).

28. The home agent of claim **27**, wherein the information within the first update message comprises the following: (i)

information identifying the correspondent node; (ii) a public key of the correspondent node; and (iii) a shared secret between the mobile node and the correspondent node.

29. A method implemented by a home agent for facilitating mobile IP route optimization, wherein the home agent interacts with a correspondent node and another home agent, wherein the correspondent node is a mobile node, and wherein the another home agent interacts with a mobile node, the method comprising the steps of:

receiving a first update message transmitted from the another home agent, the first update message comprising a care-of-address (CoA) associated with the mobile node and information indicating that the mobile node has indicated that it has a relationship with the correspondent node;

in response to receiving the first update message, transmitting a solicitation message to the correspondent node, wherein the solicitation message is requesting confirmation from the correspondent node that the correspondent node and the mobile node have a trusted relationship;

receiving a response to the solicitation message;

in response to the solicitation message, determining whether the mobile node and the correspondent node have a trusted relationship, wherein the trusted relationship exists if the data processing system determines there is an end-to-end cryptographic relationship between the mobile node and the correspondent node; and

if there is the end-to-end cryptographic relationship between the mobile node and the correspondent node, then transmitting a transmit a second update message to the correspondent node, wherein the second update message comprises the mobile node's home address (HoA) and care-of address (CoA).

30. The method of claim **29**, wherein the information within the first update message comprises the following: (i) information identifying the correspondent node; (ii) a public key of the correspondent node; and (iii) a shared secret between the mobile node and the correspondent node.

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